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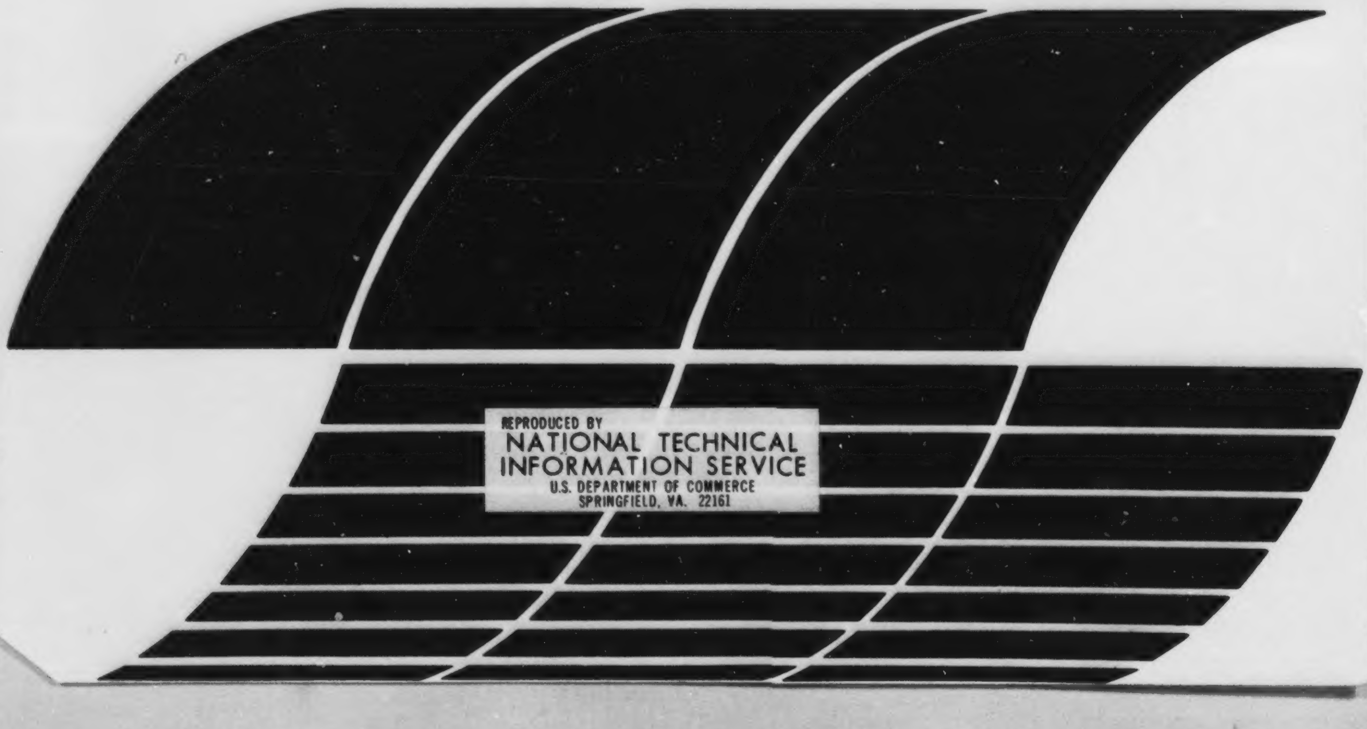

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The report provides an overview of the geography, geology, oceanography, and habitat characteristics of the study area. Summarized information on food webs, biological communities, migrations, reproductive processes, and natural stresses is provided. Major habitat types are defined and characterized by physical and biological parameters. Descriptions are provided for the structures of biological communities associated with each major habitat type; major trophic interactions; trends in organism density, community biomass and species richness; the occurrence of migrants; and the sources and magnitudes in community variability. Factors important in evaluating the relative significance of sites having certain habitat characteristics are presented. The known and potential interactions of biological communities and perturbations are discussed on a habitat type basis. Finally, an evaluation of the data base is given along with recommendations for strengthening it.

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FOREWORD

Increased petroleum transfer and refining activities are expected in northern Puget Sound and the Strait of Juan de Fuca in the future which will increase the chances of oil spills into the marine environment. A five-year multidisciplinary research project, titled "An Environmental Assessment of Northern Puget Sound and the Strait of Juan de Fuca," was initiated in 1975 to provide information usable in solving environmental questions pertaining to increased petroleum-related activities. This project was funded by the U.S. Environmental Protection Agency and administered by the Marine Ecosystems Analysis (MESA) Puget Sound Project, a part of the National Oceanic and Atmospheric Administration. This report summarizes the biological data collected in this research project as well as those collected in a similar program conducted by the Washington Department of Ecology, titled "North Puget Sound Baseline Study." The report was prepared by the principal investigators who originally collected the biological data.

ABSTRACT

This report summarizes the biological data collected during a five-year research project, titled "An Environmental Assessment of Northern Puget Sound and the Strait of Juan de Fuca." This Project was funded by the U.S. Environmental Protection Agency and administered by the U.S. National Oceanic and Atmospheric Administration. This report also incorporates biological data collected during a similar program conducted by the Washington Department of Ecology, titled "North Puget Sound Baseline Study."

The report provides an overview of the geography, geology, oceanography, and habitat characteristics of the study area. Summarized information on food webs, biological communities, migrations, reproductive processes, and natural stresses is provided. Major habitat types are defined and characterized by physical and biological parameters. Descriptions are provided for the structures of biological communities associated with each major habitat type; major trophic interactions; trends in organism density, community biomass and species richness; the occurrence of migrants; and the sources and magnitudes in community variability. Factors important in evaluating the relative significance of sites having certain habitat characteristics are presented. The known and potential interactions of biological communities and perturbations are discussed on a habitat type basis. Finally, an evaluation of the data base is given along with recommendations for strengthening it.

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SUMMARY AND CONCLUSIONS

An extensive qualitative and quantitative data base has been collected for the study area. The data emphasize the algae, invertebrates, fish, birds, and mammals of the intertidal/subtidal and nearshore habitats. Though some topical and geographic gaps in the data base exist, a relatively comprehensive understanding of the biology of the area has been developed.

The study area lies within the U.S. portion of the inland marine waters of the Strait of Juan de Fuca and northern Puget Sound (San Juan Islands and southern Strait of Georgia). Water circulation in the area is driven primarily by freshwater runoff, causing estuarine flow of surface waters out to the Pacific Ocean and deep water replacement by highly saline ocean water. This circulation pattern is modified by winds, storms, tides, and local topography.

The characteristics of the biological communities are highly dependent upon the nature of the habitats the communities are associated with. In the intertidal/shallow subtidal zones the habitats are primarily defined by the geomorphology of the shoreline. Certain communities often associate with individual shoreline types in a more or less predictable fashion. Major habitat types include: rock (including cobble), protected unconsolidated (including mud-gravel), and exposed unconsolidated (including sand and gravel). Several more narrowly-defined habitat categories exist under each major type. Habitat types are usually not discrete but, rather, grade into each other. About 50% of the shoreline is occupied by exposed unconsolidated substrates, about 40% by rock and cobble, and about 10% by protected unconsolidated substrates.

The study area is part of a large temperate biotic province that includes much of the West Coast of North America. None of the biota found in these studies are endemic to the area, though many are restricted in geographic distribution to the temperate province of the West Coast. Some biota (especially birds and mammals) are migrants and, thus, spend part of their life cycles in the study area and part elsewhere.

The 21 species of marine mammals found in the study area did not appear to have distinct habitat preferences. Harbor seals, the most common species, haul out on all intertidal habitat types where protection from human disturbance and access to prey are afforded.

Some of the species of marine birds found in the study area showed distinct habitat preferences, while others did not. Bird species richness, abundance, and biomass were generally highest in protected areas, including those with muddy intertidal habitats. Abundance was generally highest in the fall and winter and lowest in summer.

Many of the adult and juvenile nearshore fishes encountered in the study occupy several similar habitat types. Their habitat preferences often change during their life cycle. Species richness and abundance of fish were highest at protected mud-gravel habitats, such as found at Beckett Point in Discovery Bay. Biomass was highest at protected rocky reef and protected mud-gravel sites.

Intertidal benthic organisms, those occurring between the +2 m and -10 m tidal levels, were most abundant at protected unconsolidated rock and cobble sites. Since many of the species in protected unconsolidated habitats were small (e.g., oligochaetes) and those in rock habitats were large and had shells, biomass was highest at rock sites and lower tidal zone cobble sites. Species richness of benthos was highest among rock/cobble sites in the intertidal zone, intermediate at protected unconsolidated sites, and lowest at exposed unconsolidated sites. Eelgrass meadows are likely important sources of primary production. Exposed unconsolidated beaches were the most impoverished habitats because of the abrasive action of the constantly moving beach material.

Migrants may be very important to the biology of some habitat types. For example, protected unconsolidated habitats were found to be important for migratory seabirds. Pacific herring were common (in the spring) at specific sites with coarse gravel or cobble intertidal habitats. Juvenile salmon were found at exposed unconsolidated habitats. Two species of migratory sea lions occupied certain rocky sites.

Rock/cobble intertidal habitats have highly complex and diverse food web structures. Herbivorous and suspension-feeding invertebrates were common at most sites. High standing stocks of predators such as seastars, gastropods, and fish were common, preying upon herbivores and suspension-feeders. Food webs at exposed unconsolidated habitats are based upon detritus transported from adjacent kelp beds, eelgrass beds, and saltmarshes. Detritus-consuming invertebrates were most common in this biologically impoverished habitat and are often preyed upon by carnivorous invertebrates, birds, and fish. Food webs are highly diverse in protected unconsolidated habitats and are based upon detritus generated from macroalgae, eelgrass, and saltmarsh plants growing in the habitat and elsewhere. Deposit-feeding polychaetes and bivalves and suspension-feeding bivalves are preyed upon by carnivorous seastars, fish, and birds. Epibenthic zooplankton are also very important prey items for nearshore fishes in this habitat type.

The sources of variability in biological characteristics of each habitat type differed among the biotic groups. Some variability was due to sampling and data interpretation procedures; other sources were related to the natural seasonal, annual, geographic, and cyclical processes that occur among marine biota.

Nearshore habitats, defined here as the water column from the high tide line to the 20 m depth contour, supported numerous birds, fish, and mammals.

Food webs are primarily based upon phytoplankton production. Herbivorous (suspension-feeding) zooplankton are preyed upon by carnivorous zooplankton and fish, which, in turn, are prey for birds and mammals. Bird density and biomass in summer appeared to be highest in nearshore waters at exposed mixed coarse and protected rock sites. In the winter nearshore waters at protected rock and protected mud-gravel had highest bird density and biomass.

Nearshore fish density, biomass, and species richness varied widely due to episodic catches of schooling fish. Species richness was highest in spring at most sites and in the protected regions of the eastern Strait of Juan de Fuca. Densities were highest at rock and cobble sites in the spring and summer and along the Strait. Density values generally followed those of species richness. Harbor seals occurred in all nearshore habitats year-round. Some cetaceans (whales and porpoises) frequented these areas while foraging, and sea lions were found there in winter months, especially in the Strait.

The offshore waters, defined here as greater than 20 m deep, occur in the outer parts of bays, in narrow passages, in broad passages, and in open regions (e.g., western Strait). About 88% of the water surface in the study area covers depths greater than 20 m.

The offshore food webs are similar to those of the nearshore waters; they are based upon phytoplankton production and successive consumption by zooplankton, fishes, birds, and mammals. Diatoms contribute to much of the phytoplankton biomass. Large quantities of copepods, juvenile fish, fish eggs, and invertebrate larvae occurred among the zooplankton. Offshore bird populations were composed of large numbers of a relatively few species when compared to nearshore habitats. Loons, grebes, murres, cormorants, ducks, and gulls were common. The majority of many of these species wintered in offshore waters. Small populations of minke and killer whales and sea lions were important top carnivores in offshore waters. Western Grebes were abundant in offshore bay waters; Brandt's Cormorant, Bonaparte's Gulls, and Arctic Loons were abundant in narrow passages; Common Murres and Rhinoceros Auklets were common in broad passages and open waters.

The factors which are important in evaluating the relative biological significance of a site vary according to the habitat type. A list of "Importance Factors" was generated and described and examples were given. Though some sites with definable habitat characteristics may be found to be highly important to marine biota, all sites and all habitats are parts of an overall system and, as such, are not necessarily expendable. The importance of some sites with certain habitat types goes beyond the study area. For example, migratory salmon, seabirds, and marine mammals enter the area yearly from other North American areas or other continents. Many populations of invertebrates are important as brood stock for colonization of adjacent areas. At least 12 subregions are identified as unique in terms of the abundance and/or type of biota found there.

The study area is generally free of pollution and other human perturbations, though the effects of some human activities have been documented. The actual and potential effects of perturbations vary according to the type of stress. The habitats most susceptible to stress also vary accordingly. However, protected bays and unconsolidated intertidal/subtidal habitats appear to be most sensitive, especially to the effects of oil. The consequences of oil spills and other perturbations may be either immediate and acute or long-term and subtle; and they may be either magnified or partially mitigated by some other stress.

While the data set collected during the Washington Department of Ecology (WDOE) and Marine Ecosystems Analysis (MESA) studies is extensive, a number of data gaps became apparent during the studies and during this synthesis. Nearby geographic areas where no similar comprehensive data set was collected include the Saratoga Passage/Skagit Bay area, outer coast, Admiralty Inlet, the central and southern basins of Puget Sound, and Hood Canal. Topical gaps include characterizations of: meiofauna; saltmarshes; offshore deep benthos; nearshore plankton; offshore fish; nearshore/rocky kelp bed fish; and cetaceans. Additional data are also needed to understand the ecological relationships of the biological communities in the study area and the rates and limiting factors in processes, such as primary, consumer, and detritus production.

I. INTRODUCTION

An extensive biological data base has been developed in the Strait of Juan de Fuca and northern Puget Sound area (Figure 1) under research programs sponsored by the U.S. Environmental Protection Agency (EPA), administered by U.S. National Oceanic and Atmospheric Administration (NOAA) and the Washington Department of Ecology (WDOE). Data were collected during numerous separate studies conducted from 1974 through 1979. These studies were initiated in response to anticipated increases in the use of the area for transport and/or processing of crude oil. The objectives of the studies were to characterize the major components of the marine biota of the area and, if possible, to establish a quantitative baseline against which changes caused by any significant petroleum-related perturbation could be measured.

The majority of data-collecting activities were terminated by the end of 1979, though some monitoring activities will likely continue into the 1980s. Research was conducted to characterize the algae, macroinvertebrates, fish, birds, marine mammals, and plankton. The results have been published in a series of technical documents (Appendix Table I-A) and two summary reports (Gardner, 1978; Long, 1980) available through the respective sponsoring agencies. However, since each technical document only deals with a restricted biologic group, their utility individually in shoreline management, project planning, and habitat protection decisions is restricted. Also, the utility of all the documents together is limited, since the individual studies were not always conducted in the same areas, during the same times, or using comparable or compatible methods. Finally, some of the observations made and conclusions formed by the individual investigators were not necessarily reported in any of the technical documents, and thus are not readily available to users.

The overall objective of this document is to provide a compilation and synthesis of the major results of the biological studies performed under the sponsorship of EPA/NOAA and WDOE, such that the results can be more easily used in decisions and policies regarding shoreline management, resource utilization planning, research project planning, and habitat protection. Though these data were collected with the primary intent of applying them to estimates of potential and actual biological changes caused by petroleum-related activities, they can also be used in assessing other types of projected perturbations.

This document was planned, assembled, and written by a multidisciplinary team, composed of the original principal investigators of the EPA/NOAA and WDOE sponsored biological studies. The expertise of the team included marine mammalogy, ornithology, fish ecology, benthic ecology, and trophic dynamics.

Each team member was responsible for providing his or her expertise to the team, as well as analyses and interpretations of other data sets.

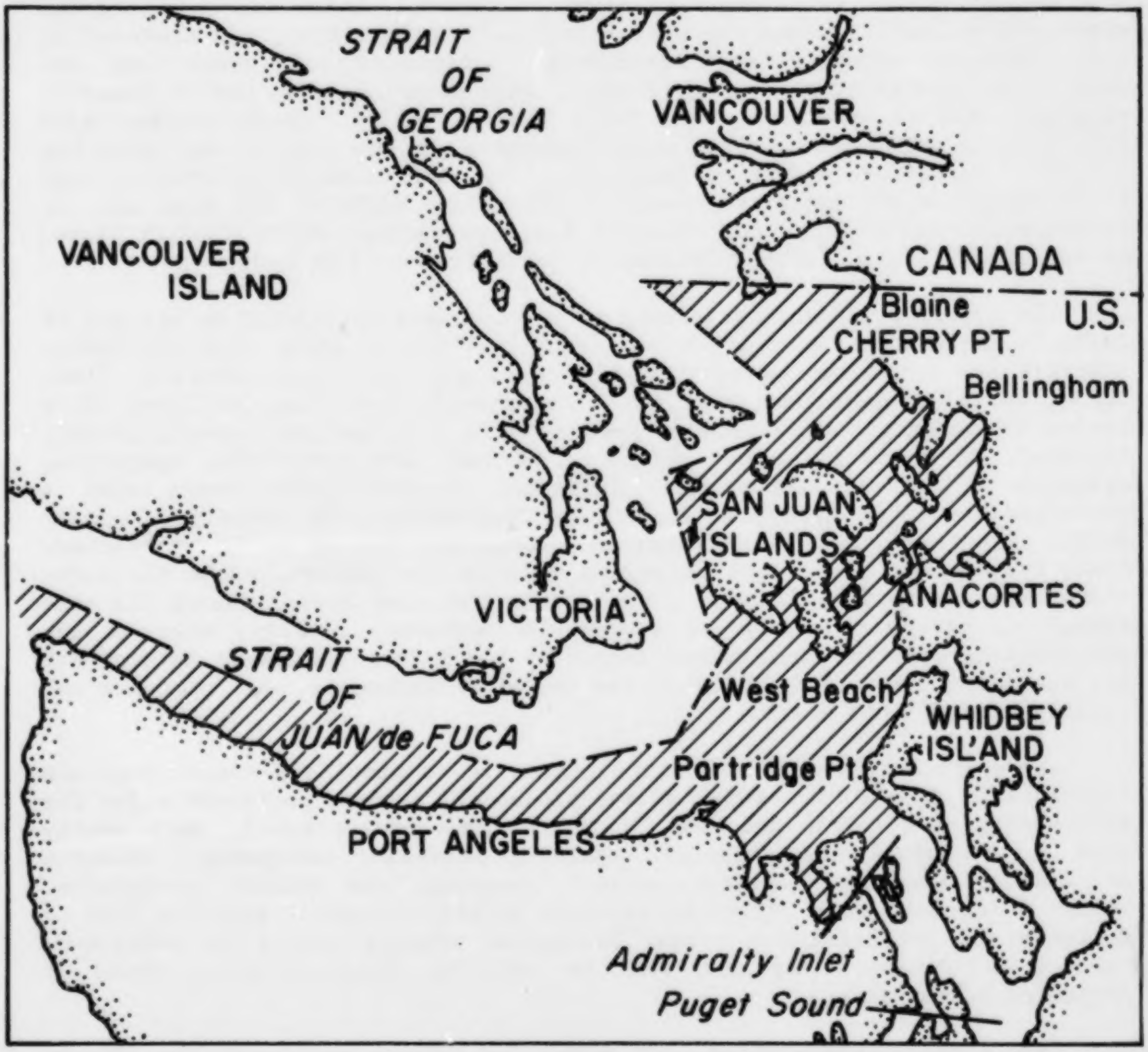

STRAIT OF GEORGIA
VANCOUVER
VANCOUVER ISLAND
CANADA
U.S.
Blaine
CHERRY PT.
Bellingham
SAN JUAN ISLANDS
ANACORTES
VICTORIA
STRAIT OF JUAN de FUCA
West Beach
WHIDBEY ISLAND
Partridge Pt.
PORT ANGELES
Admiralty Inlet
Puget Sound

Figure 1. Primary study area (shaded).

II. CHARACTERISTICS OF THE STUDY AREA

II. A. Scope

This document focuses upon the U.S. waters and shorelines of the Strait of Juan de Fuca, San Juan Islands, and southern Strait of Georgia (Figure 1). This area extends from Cape Flattery east to Point Wilson, north to the Canadian border. The area includes the marine waters between Bellingham and Anacortes, but excludes the areas east of Whidbey Island. The relationships of the study area to Puget Sound, Admiralty Inlet, Pacific Ocean, and Canadian portions of the Strait of Juan de Fuca and Strait of Georgia will be expressed where data are available.

Emphasis will be placed upon the intertidal/shallow subtidal (+2 m to -10 m) benthos and tidepool fish; nearshore (0 to -20 m) fish, marine birds and marine mammals; and open water (> 20 m) birds and mammals of the region (Figure 2). Some open water plankton, pelagic fish, and deep benthos data will be included, but not emphasized. Since the majority of the data were collected in nearshore and intertidal habitats, those areas will be emphasized.

Quantitative data collected as components of the NOAA and WDOE sponsored projects will be used as the primary information sources, supported by other data sets that are applicable to the area and the objectives of this synthesis. Most quantitative data were archived in standardized computer formats by investigators supported by the NOAA/MESA Puget Sound Project.

Additional NOAA sponsored research concerning the oceanography of the Strait of Juan de Fuca, the behavior of surface drifters, the existing levels of petroleum hydrocarbons, the processes that influence the fate of hydrocarbons, and the effects of crude oil upon recovery of intertidal communities has been conducted. These research projects have been reported elsewhere and will not be included in this synthesis, though some conclusions from these projects will be utilized in discussions of the oceanography of the area and of the consequences of oil spills. Reports of these projects are available through the NOAA/MESA Puget Sound Project Office.

II. B. Geologic History

The geologic history of the study area has involved three basic kinds of processes. The basic structure is the result of regional tectonic processes, where the movements of the earth's crustal plates have resulted in stresses upon and upheavals of the surface. The major landforms and shape of the surface are the result of glaciation during the Pleistocene Epoch. The shape

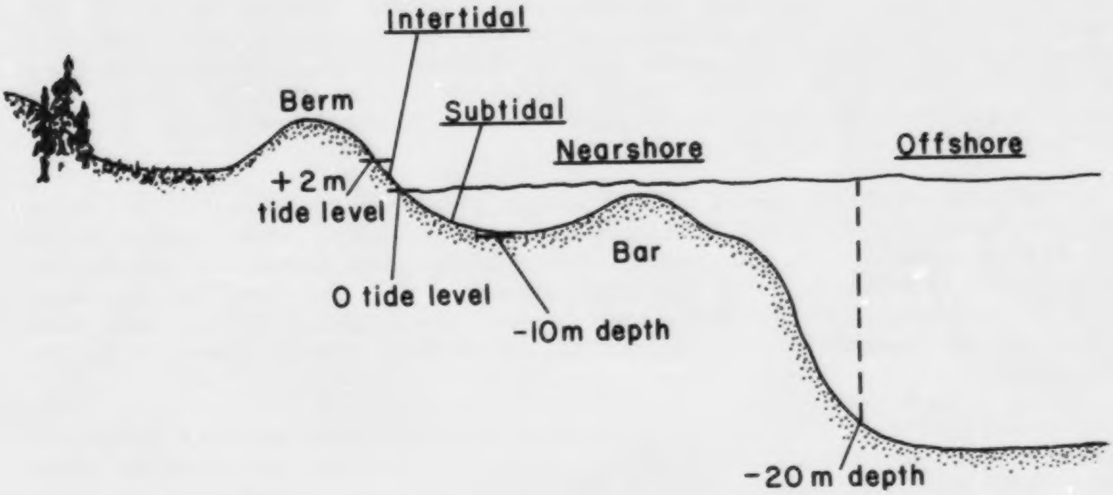

Intertidal
Berm
Subtidal
Nearshore
Offshore
+2 m tide level
0 tide level
Bar
-10m depth
-20 m depth

Figure 2. General characteristics of an exposed unconsolidated beach.

of beaches and shorelines has been further modified by post-glacial sea-level changes and the action of riverine and marine shoreline erosion.

The structural development of the western ranges of North America, including the Cascades and Olympics of Washington and the Insular Mountains of Vancouver Island, took place during the Cordilleran mountain-building process. During a period beginning about 200 mybp (million years before present), interactions between western North America and the oceanic area of the Pacific took place in a zone of crustal convergence marking the intersection of two crustal plates. This convergent interaction gave rise to a sequence of events which resulted in a westward building (accretion) of North America's western boundary as new crust was added to the continent.

However, several anomalous features do not clearly fit into a general description of the major structures, principally the transverse (east-west) trend of the Strait of Juan de Fuca and the extreme age of some of the rocks found in the San Juan Islands. These local structural trends appear to be related to differences in rates and type of convergent plate processes caused by interaction of the Juan de Fuca plate and the western margin of North America. At any rate, the fundamental structural framework was established by 50-25 mybp with the development of the Olympic Mountains.

Pleistocene glaciation had a major effect on shaping the surface form of the study area. On a global scale, the Pleistocene was marked by four major advances of glacial ice moving across northern North America and Europe. Locally, this epoch was marked by persistent glaciation by alpine glaciers in the Cascades, Olympics, and Insular Mountains, but the dominant invasion of the region was by the Cordilleran Ice Sheet. This center of glaciation occurred during the same period of time as the major continental glaciers that moved over central and eastern North America. However, it was independent in origin, resulting from accumulation of glacial ice originating in the mountains of British Columbia and on Vancouver Island. This accumulation of ice filled the Georgia Depression and, impeded by the Insular Mountains of Vancouver Island, moved out of the Georgia Depression around Vancouver Island. The southward moving ice overran the San Juan Islands, scouring even the highest hills, and moved to the eastern end of the Strait of Juan de Fuca. Here its progress was stopped by the Olympic Mountains and the ice split into two lobes. One, moving south into the Puget Lowland, is termed the Puget Lobe and played a dominant role in the formation of Puget Sound. The other, the Juan de Fuca Lobe, moved seaward out through the Strait of Juan de Fuca.

The effects of this glacial activity are very evident in the study area. The smoothing and rounding of the San Juan Islands, erosional deepening of Haro Strait, East Sound, and Rosario Strait, and glacial grooving in many places are evidence of the erosive power of the ice which covered the San Juans to a depth of more than 700 meters. Depositional processes left much of the eastern and southern portion of the Puget Lowland buried under a great thickness of glacial deposits. To a lesser degree, the deposits from the Juan de Fuca Lobe are found along the shoreline of the Strait in many localities. Many of today's shoreline features and marginal deposits along

Whidbey Island, near Dungeness Spit, on northern Quimper Peninsula, and elsewhere show clear evidence of their glacial origin.

Following the final retreat of the Cordilleran Ice Sheet, recent and on-going wave action, worldwide sea-level changes, and deposition of riverine sediments modified the shorelines to today's conditions. The relative importance of the processes varies geographically. Vigorous wave action has eroded rocky headlands and formed wave-cut benches in the western Strait of Juan de Fuca. Recent increases in sea level have resulted in submergence of some shoreline features. Deposition of riverine sediments has created broad tidal flats in some areas, particularly in the Bellingham Bay/Padilla Bay area.

II. C. Geologic Setting

The coastline of the study area consists of distinct forms: rocky shores, sand, gravel and cobble beaches; gravel and sandspits; mudflats and mixed mud beaches in protected bays and harbors. The recent material that formed the shorelines has come from three main sources: (a) erosion of rocky headlands (e.g., the San Juan Islands and much of the Strait of Juan de Fuca); (b) redistribution of unconsolidated material deposited by glacial action (e.g., Whidbey Island); and (c) deposition of riverine sediments (e.g., Padilla Bay).

Rocky headlands erode slowly relative to unconsolidated shorelines and bluffs. The rate of erosion, however, is increased by abrasion from waterborne materials such as logs, sand particles and flotsam; waves; repeated freezing and thawing of water in the cracks of rocks; and the boring activities of animals such as urchins and molluscs. Tides and storms also greatly increase the rate of wave erosion. The large waves driven by storm winds during periods of high tides most likely carry the maximum of waterborne materials. In some areas, such as the western part of the Strait where large waves are common, wave-cut terraces occur commonly on rocky shores.

Waves, winds, and repeat freezing and thawing also cause erosion of glacial deposits, usually found in the area as bluffs. Where wave action and littoral drift (long-shore currents) are adequate to suspend the eroded material, transport and redistribution take place. Littoral drift is produced by the energy of waves striking the shore at an angle, tidal currents, winds, and net estuarine flow. Transport of these materials will occur as long as sufficient turbulence exists to keep them suspended. Deposition often occurs in areas of low turbulence, such as in the lee of a sand spit or in a protected embayment. This deposition may lead to further growth of a sand spit, such as at Dungeness Spit. Resuspension may occur during episodes of strong winds, waves, or currents. The finest, lowest density particles remain suspended the longest.

The beach is not well-developed in areas with active erosion. A wavecut terrace is usually the dominant feature of the intertidal zone at erosional beaches. The beach proper is generally a narrow belt near or at the high tide line. There is no backshore development. At beaches where there is neither active erosion nor accretion of material, but where longshore transport is present, the foreshore is relatively steep, no offshore bar forms, and the backshore is not well-developed. In areas of active accretion of sediments, beaches show their greatest development: the foreshore is well-developed and relatively wide, offshore bars may be present, and the backshore is characterized by berms and sand dunes (Figure 2).

Riverine particles consisting of glacial deposits, sediments eroded from uplands, and organic debris arrive at the estuaries in greatest volume during periods of high flow. Where these particles are exposed to adequate longshore currents and energy, they remain suspended for a considerable time, are transported for many kilometers, and may be eventually deposited in a bay or harbor or some other area where currents are weaker. However, where riverborne sediments enter a protected estuary, they are rapidly deposited in the mixing zone where freshwater and saltwater meet. Marshes and/or deltas with shallow offshore flats may then be produced. Eelgrass and marsh plants tend to accelerate sedimentation by reducing wave energy and long-shore currents.

Due to the forces of erosion and accretion, the coastline is constantly changing with time. In some areas the change is rapid. Actively eroding cliffs and sand or gravel spits may increase or decrease up to a meter per year. Other areas such as rocky shorelines erode slowly. Gravel or sand beaches acting primarily in sediment transport may accrete or erode only millimeters per year.

II. D. Physical Oceanography

The study area is decidedly marine in character with water salinity approaching that of the Pacific Ocean (29 to 31 parts per thousand °/oo). Salinity is often lowest in the eastern and northern portions due to the influence of the Fraser River and other freshwater sources. Surface temperatures range between 8 °C and 11° C; the west portion of the Strait of Juan de Fuca is warmest due to the influence of Pacific Ocean water. Temperature and salinity are often relatively uniform from the surface to the bottom in the deep channels during the winter. During the summer a weak pycnocline (density layer) often forms at 50-100 meters, and surface-to-bottom temperature differences approximate 4 °C and salinity differs by about 3°/oo. This water column structure appears to be influenced mainly by salinity and is easily disrupted by fall and winter storms, at which time considerable vertical mixing is possible. Small-scale horizontal variations in water characteristics can be influenced by tributaries, tidal eddies, upwelling, downwelling, local winds, tidal fronts, bathymetry, and embayments.

The Strait of Juan de Fuca is a weakly stratified, partially mixed estuary with a surface-to-bottom salinity difference of 2-3°/oo, a 3-4 meters spring tide height, and strong tidal currents of 77-154 cm/sec (1½-3 knots) (Herlinveaux and Tully, 1961; Rattray, 1967). The estuarine circulation in the Strait consists of a well-developed two-layer pattern, with near-surface velocities directed westward at 20-40 cm/sec and deep layer velocities directed eastward at 10 cm/sec. Over time scales of 4-6 hours, tidal currents dominate the flow regime. Currents of 200-250 cm/sec (4-5 knots) are common in the more restricted passageways of the San Juan Islands and in Admiralty Inlet. The along-strait mean flow is characterized by the classical estuarine circulation with westward transport near the surface and eastward transport near the bottom (Figure 3).

The circulation of the southern Strait of Georgia and San Juan Islands area is poorly documented. However, the influence of the Fraser River is very evident and adds to the net southward transport of surface water through Haro and Rosario Straits and, to a lesser degree, through the San Juan Archipelago.

Nearshore currents (or littoral drift) are poorly known in the study area. However, a few generalizations can be formed from existing data. Eastward transport of suspended sediments and floating materials along the southern shore of the strait is indicative of the eastward drift there. Ediz Hook and Dungeness Spit have formed by deposition of material originating from the west. Littoral drift in the southern Strait of Georgia and San Juan Island area is highly variable, but net transport is southward.

Water currents in the area are caused by freshwater runoff, tides, and winds. The circulation in the deep channels is maintained by river water which enters and sets up a longitudinal sea-surface slope directed seaward. The near-surface flow is driven primarily by this slope, while the deeper flow is driven by the longitudinal density gradient. These two driving forces are balanced by the internal and bottom frictional forces generated by the strong tidal mixing. Freshwater input is primarily from the Fraser River through the Strait of Georgia and tributaries to the main basin of Puget Sound. The Fraser River accounts for approximately 70-75% of the freshwater discharging into the Strait of Juan de Fuca (Herlinveaux and Tully, 1961). Most of the riverine drainage areas are high mountain regions, and winter snow storage plays a major role in establishing the runoff which normally commences with spring thaws in March and attains maximum discharge in July. Prior to entering the eastern basin of the Strait of Juan de Fuca, these diluted freshwater sources are tidally mixed in the passages leading through the San Juan Archipelago and across Admiralty Inlet. This tidal mixing, therefore, has a moderating effect on the seasonal salinity fluctuations in the strait.

Tidal currents dominate the flow regime in the study area. They constitute navigational hazards and tend to disperse floating and dissolved constiuents away from shorelines and to concentrate them in nearshore eddies and fronts. Both the diurnal and semidiurnal tides enter the strait from the Pacific Ocean as a progressive wave and propagate eastward where their interactions lead to semidiurnal mixed tidal currents in the eastern basin. As each wave propagates through the topographically complicated San Juan Archipelago, it produces complex current patterns in this region with strong tidal currents in Haro and Rosario Straits and Admiralty Inlet.

The predominant winds along the Washington coast are southwesterly (from the southwest) in the winter and northwesterly in summer paralleling the general coastline. In the Strait of Juan de Fuca the winds are strongly influenced by orographic (mountain) effects and tend to be directed along the

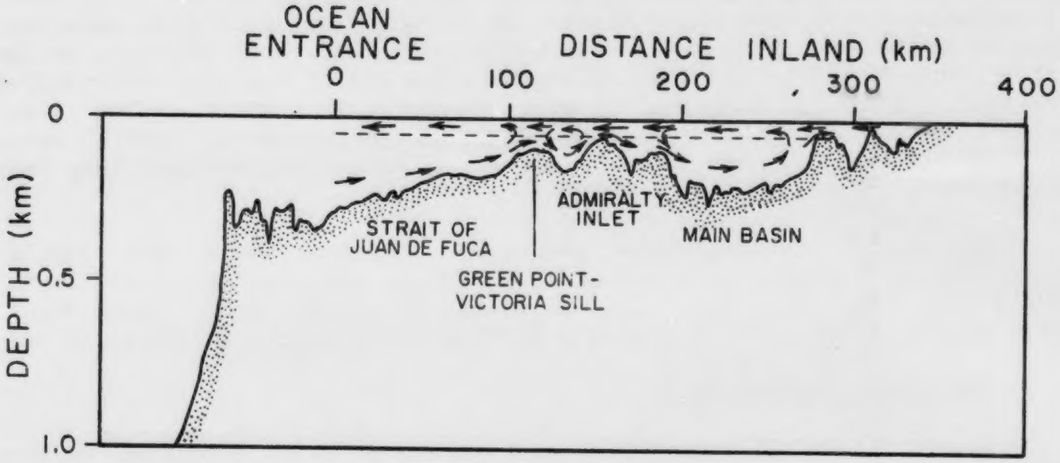

OCEAN ENTRANCE
DISTANCE INLAND (km)
0
100
200
300
400
0
0.5
1.0
DEPTH (km)
STRAIT OF JUAN DE FUCA
GREEN POINT-VICTORIA SILL
ADMIRALTY INLET
MAIN BASIN

Figure 3. Profile view of net circulation at mid-channel in summer between the Pacific Ocean and the head of Puget Sound (from Ebbesmeyer et al., 1979). Notation: dashed line equals depth of no-net-motion (approximately 50 m).

axis of the Strait. During summer, the northwest coastal winds are funneled up-strait (eastward) and generally decrease in strength with distance eastward. Over 75% of all winds at Port Angeles during summer are from the western quadrant. Winds over the San Juan Island/southern Strait of Georgia area are generally from the south or southwest, except in the winter when northerly winds occur over Haro Strait and west of it.

Winds play only a weak role in modifying near-surface circulation (Holbrook et al., 1980). However, results from surface drift sheet and drift card studies (Ebbesmeyer et al., 1979) suggest surface winds are an important small-scale factor in the dispersion and transport of surface trapped contaminants. By contrast, strong southwesterly winds associated with episodic storms dramatically affect near-surface circulation (Holbrook and Halpern, 1977; Holbrook et al., 1980). The effect of these storms in the Strait of Juan de Fuca is that the usual seaward estuarine flow in the surface layer is reversed, causing eastward intrusions of warmer ocean water and retention of surface water within the system. The intrusions have been observed for periods of up to 10 days with maximum speeds of 20 cm/sec as far east as Dungeness Spit and they occurred during 35% of the time observations were made. Satellite infrared imagery indicate the intrusions may reach eastward as far as Whidbey Island. Although intrusions of coastal water generated by coastal southwesterly winds are common during winter, they have been observed year-round.

The complex oceanographic processes outlined above are further complicated in numerous local areas by upwelling, downwelling, tidal fronts, eddies, and other features. In the event of an oil spill these highly unpredictable features could play a significant role in the transport of oil.

II. E. Biological Oceanography

All the biological communities and processes to be discussed in this report are directly or indirectly influenced by numerous oceanographic processes. Some of the physical oceanographic processes were discussed above. Unfortunately, very little is known of the biological oceanography of the study area, though data exist for the adjacent waters of the Puget Sound central basin and the Strait of Georgia.

The factors that control phytoplankton production are numerous and the relative importance of each varies geographically. Stockner et al. (1979) ranked grazing, nitrates, and light in decreasing order of importance for the Strait of Georgia. Winter et al. (1975) found that nitrates control and stimulate primary productivity and rarely, and only briefly, become exhausted and limiting following intense blooms in the Puget Sound central basin. Certainly, all these factors and others work in combination to regulate the timing and rates of primary productivity. Stabilization and stratification of the water column and increased sunlight are necessary in the spring to stimulate phytoplankton blooms. Replenishment of depleted nutrient levels during the fall and winter months must occur so that elevated nutrient levels exist when the sunlight and water column conditions are optimal. Nutrient replenishment occurs primarily as a result of advection and mixing of oceanic water (Winter et al., 1975) or, in the vicinity of major rivers such as the Fraser, as a result of runoff (Stockner et al., 1979).

Water column stratification is most distinct in the deeper areas and rarely occurs in the narrow and shallow channels and passages separating land masses. Stockner et al. (1979) found that a distinct halocline existed during the winter throughout the Strait of Georgia, except in the turbulent passages of the San Juan Islands and Canadian Gulf Islands. They found that nutrient levels were highest in these well-mixed areas. Turbulence and mixing in these passages is a result of strong tidally-induced currents.

Phytoplankton blooms in the area seem to begin most often in April or May (Stockner et al., 1979; Winter et al., 1975) though a major bloom was noted in June of 1976 and none was observed during bimonthly surveys in 1977 (Chester et al., 1980). Stockner et al. (1979) estimated that mean annual production varied from 150 g C/m^2 in the Fraser River plume to over 500 g C/m^2 in sheltered waters of inlets and averaged 345 g C/m^2 for the Strait of Georgia, but, later, estimated annual production at 250-350 g C/m^2 (Stockner et al., 1980). Parsons et al. (1970) estimated annual productivity to be about 120 g C/m^2 and, later, argued that the estimates of Stockner and associates were incorrect (Parsons et al., 1980). Winter et al. (1975) estimated annual productivity for Puget Sound to be about 465 g C/m^2 and attributed the high rate to persistent upwelling of nutrients and viable algal cells.

Diatoms appeared to be the major component of Strait of Juan de Fuca phytoplankton communities during the mid-spring and early summer; whereas microflagellates were dominant in late fall and winter months (Chester et al., 1980). Diatoms appeared to be dominant in the Strait of Georgia during the spring and fall, while dinoflagellates were common in August (Stockner et al., 1979). Drastic changes in phytoplankton composition and density occur spatially and over short (two week) periods, as many species seem to occur in patches.

While water temperatures, nutrient levels, and salinities generally are uniform throughout the study area, local phenomena such as the influence of rivers, upwelling in turbulent passages, sewage outfalls, and tidal fronts may cause considerable variations in these parameters in small areas. The productivity and composition of biological communities often vary in response to these local situations. For example, nutrients and prey are brought to the surface by turbulence in narrow channels and over sills, and thus create attractive feeding areas for marine birds. Productivity is also often high in protected embayments where nutrients and organic matter are delivered by rivers or sewage inputs or produced by in situ degradation or organic debris. Water temperatures are often relatively high in protected embayments due to warming by the sun and negligible flushing, possibly increasing microbial degradation rates.

Production of macroalgae which occur over much of the hard-substrate intertidal, subtidal, and nearshore zones, although limited in areal extent to the lighted depths, may actually match or surpass that of phytoplankton. The contribution of attached plants to total carbon production is greatest in shallow bays where eelgrass (Zostera marina) thrives, along rocky or cobble shores and over shallow rocky reefs where macroalgae are abundant.

Webber (1981) summarized the small amount of plant productivity data available for the study area. Most marine plants are annuals. Growth begins in early spring, is maximum in spring and summer, and declines to a minimum in winter. Timing of growth and productivity varies from species to species. A production rate of up to 100 g wet weight biomass per day per plant was measured in May for Laminaria saccharina in experiments conducted near Anacortes. In the same studies, a rate of 250 g wet weight biomass per day per plant was measured in August and September for Nereocystis luetkeana.

The eelgrass Zostera marina is estimated to cover about 9% of the bottom of Puget Sound or some $4.5 \times 10\ m^2$ (Phillips, 1974). He calculated that eelgrass beds fixed 1.5 g C/m^2/growing season day, resulting in an annual production of 187-1078 g/m^2.

While much of the plant material produced in the marine environment is consumed by grazers, 35-40% of the gross production may be liberated into the sea as dissolved organic matter. Perhaps the most important contributions that marine plants make to the ecosystem are as a source of detritus and as shelter and a substrate for attachment for a wide variety of organisms.

II. F. Biogeography

The study area is part of a large temperate biotic province that includes much of the West Coast of North America. There is considerable disagreement concerning the boundaries and name of the province. The area lies roughly in the middle of the Temperate Northwest American faunal province which extends from the Aleutian Islands, Alaska south to Point Conception, California (Sverdrup et al., 1942). Several authors suggest the area is included in either an Aleutian, Oregonian, Temperate, or Oregonic province that variously extends from as far north as the northern end of the Gulf of Alaska south to Cape Flattery or thereabouts (Hedgpeth, 1957). The most inclusive boundaries may be particularly reasonable for mobile animals such as some fishes, birds, and marine mammals since they are the groups least restricted in geographic range. The habitats of the study area apparently support very few or no endemic species; but many of the invertebrate and fish species found there occur only in protected marine or estuarine waters. The study area represents one of the largest expanses of protected, relatively shallow water of an estuarine character found along the West Coast of North America. Therefore, it is of considerable importance to marine biota that require a protected environment. All occur extensively in the temperate latitudes of the West Coast of North America and in some cases beyond to other continents.

The study area may represent the end of the southern or northern range of some species. Except for migratory animals, the biological communities in the study area are very dissimilar to those found in the tropics, but some species found in the area also occur in the colder boreal latitudes.

The phytoplankton and zooplankton of the study area are not endemic, but represent a varying mixture of species which are typically associated with open-ocean, protected marine and estuarine environments. Many of the attached flora are endemic to the West Coast of North America (Abbot and Hollenberg, 1976). The kelps are notable in this respect, although many genera have representative species elsewhere. The seagrasses (e.g., Zostera marina) are not endemic (Kikuchi and Peres, 1977).

Among fishes in coastal North America, the order Scorpaeniformes is particularly well-represented. The families Scorpaenidae, Cottidae, Agonidae, and Liparidae all have many endemic West Coast species. The family Embiotocidae is endemic to the North Pacific, and nearly all of its species are found in North American waters (Ekman, 1953). Several other groups, including salmonids, osmerids, and clupeids, also have characteristic species in this region.

Among marine mammals there is also a reasonably distinct northeast Pacific fauna. Many of the species that are present in other parts of the world are represented in this area by distinct subspecies. Some of the species undertake long migrations from breeding areas to richer northern feeding areas, and their contribution to the species assemblage of a particular location is highly seasonal. Gray whales, for example, migrate annually between Alaska and Mexico (Everitt et al., 1980).

Marine birds are even more mobile than fishes or most mammals, and do not fit as well into the biogeographical boundaries that are useful for other groups. Almost all species found in Puget Sound migrate seasonally to some extent. The most prevalent pattern is migration n orth and south along the North American coasts, dispersing inland in early summer to nest in boreal and arctic North America. Nearly all species which breed in the area, including various alcids, cormorants, and the Glaucous-winged Gull, nest on relatively small coastal islands. A few species, such as the Lesser Snow Goose and Common Pintail, have populations that migrate to eastern Siberia to nest and winter in coastal North America (Palmer, 1976).

Although this high degree of mobility complicates efforts to characterize bird species assemblages, several points emerge. First, very few species that winter here are restricted to the West Coast of North America, and none are unique to Puget Sound. Second, most of the species found along the North American coasts are primarily found in relatively shallow, protected waters. Concentrations of food in estuaries and along tidal fronts may also constitute preferred habitats, and allow increased species richness and abundance over open water habitat. Finally, the timing of migration creates assemblages of species which vary substantially over time and space, but which are nevertheless reasonably predictable over an annual cycle.

III. BIOLOGICAL COMMUNITY ORGANIZATION AND MAJOR ECOLOGICAL PROCESSES: AN INTRODUCTION

III. A. Concept of Biological Communities

A suite or group of closely ecologically associated organisms compose a biological community. Ecologically closely associated communities, in turn, form the biological component of an ecosystem. The biota composing these communities, in interaction with the physical processes, are described in composite as an ecosystem. This sytem is characterized by a trophic structure (food web), energy flow through that structure, cycling and recycling of minerals, diversity patterns in time and space, community control processes (e.g., predation, reproduction, competition), succession, and internal control processes. The primary focus of this synthesis is the biological components of the marine ecosystems of the study area, and the following discussions will focus upon distinguishable biological communities which have been identified and characterized.

Since functional processes, rather than geographical boundaries, characterize biological communities, we have attempted to view communities on the basis of organization and trophic relationships. Thus, those biota which illustrate similar community structure and function, although often physically separated in the region, will be considered as representing a common biological community. Thus, any single community may be found at numerous locations.

Biological communities will be categorized primarily according to the dominant physical conditions. That is, a number of diverse habitats represented on a relatively large regional scale will be used to illustrate differences in biological communities. For example, intertidal/subtidal communities will be categorized according to sediment type and exposure. Where the habitat is characterized by a single, visibly prominent feature (e.g., kelp beds and eelgrass meadows), these terms will be used to delineate the biological communities or modify the category.

The use of physical habitats to delineate communities is justified since many species show distinct preferences for certain physical conditions. Comunity structure and trophic structure can be fairly similar at widely separated places when physical conditions are similar. Therefore, each habitat type can support distinct groups of organisms although boundaries between these communities usually are not clear-cut. Habitats typically grade one into the other; and, therefore, the communities do as well. Biological communities described in this report are thus representative of the continuum of habitat, community structure, and function throughout the study area.

III. B. Food Web Structure

Organic matter and energy are transferred and changed in biological communities primarily by feeding or "trophic" interactions among producer, decomposer, and consumer organisms. The pattern of material and energy flow from the production and decomposition levels through the various consumer levels is commonly referred to as a "food web." Food webs are typically complex. Most predators consume many species of prey, often at several trophic levels. Any single prey species may be eaten by many predators. Lateral linkages, where one species consumes another of an equivalent trophic level, or feedback linkages, where prey-predator relationships are reversed during certain life history stages, may occur. The early concept of a food chain, with single species prey-predator linkages, is now considered an oversimplification, as such a food chain is relatively uncommon in nature.

III. C. Trophic Levels

Food web structure is characterized by organisms which synthesize, decompose, or consume organic matter. The synthesizers (or producers) and decomposers each constitute a "trophic level," while several trophic levels may occur among the consumers.

Primary producers, plants which fix carbon by means of photosynthetic processes, compose the "lowest" trophic level. The process of photosynthesis involves conversion of carbon dioxide and water, using light as an energy source in the presence of chlorophyll, into organic matter, with a corresponding release of molecular oxygen. The principal primary producers found in the study area include bacteria, phytoplankton, benthic diatoms, various macroalgae (including the large kelps and foliose red, brown, and blue-green algae), and vascular flowering plants such as marsh plants and seagrasses. Since photosynthesis is light-dependent, primary production in the study area is greatest in spring and summer and lowest in the winter.

Decomposers occupy a trophic level parallel to that of the primary producers. Decomposers (or reducers) are microorganisms, usually bacteria or fungi, which break down complex organic material into the simpler compounds necessary for primary producers; this process may be either aerobic (with oxygen) or anaerobic (without oxygen). Decomposition may be facilitated by physical abrasion and grinding.

Consumer organisms can be categorized by the types and number of trophic linkages occurring between them and a source of primary production. Animals consuming primary producers directly are considered primary consumers, also termed grazers or herbivores. Further categorization may be made based upon the organisms' feeding strategies and the size of the food particles consumed. Suspension feeders remove suspended phytoplankton and other food particles from the water, while true grazers directly ingest particles of attached microalgae, macroalgae, or vascular plants. Thus, primary consumers can include organisms from the smallest pelagic copepods which "graze" on phytoplankton to geese which feed on seagrasses.

Secondary and higher level consumers are animals which prey upon other animals and are referred to as carnivores. Primary carnivores feed on primary consumers, secondary carnivores feed on primary carnivores, and so on. The animals which occupy the top of this network of trophic levels are termed the top carnivores and are not consumed by other carnivores. In short food webs, the top carnivores may constitute only secondary consumers but typically are tertiary carnivores.

Dead organic matter and the bacteria which break it down provide a food base for a series of trophic levels similar to those based upon primary production. A variety of feeding strategies are known for detritivores (detritus consumers). Some species can directly graze on organic particles, some on the bacteria, and some can prey upon other detritivorous animals.

The "classical" marine food web was historically considered to be based upon autotrophic production of carbon by phytoplankton; consumption of phytoplankton by herbivorous zooplankters with subsequent consumption by carnivorous zooplankters; and so on up the food web. This classical food web was based upon offshore research and appears to be correct for open water pelagic systems. This early concept has changed with the recent shift in research emphasis from oceanic ecosystems to emphasis on shallow nearshore ecosystems. It appears now that shallow water marine food webs are largely based upon the heterotrophic processing of detritus produced by the senescence of marine algae and estuarine and saltmarsh vascular plants. The contribution of eelgrass to the pool of detritus has been especially implicated as a major source of organic carbon to nearshore food webs in the temperate waters of the North Pacific Ocean (McRoy, 1970; Kikuchi and Peres, 1977; McConnaughey and McRoy, 1979a,b). Although grazing herbivores such as sea urchins, isopods, and brachyuran crabs directly consume macroalgae and vascular plant vegetation in the nearshore environs, most of the primary level consumers appear to be detritivores (Simenstad et al., 1979). Thus, while some algal organic matter is directly transferred to upper trophic levels via these grazers, most of it reaches maturity, becomes detached, and ends up decomposing on the beaches and in shallow subtidal zones. It eventually forms a pool of suspended and dissolved organic carbon available for colonization by microflora. Not all detritus is directly utilizable by marine detritivores because most marine invertebrates lack adequate enzymes to digest it. Thus, structural and nutritional decomposition of the particles by marine bacteria and fungi appears to be a critical process in conditioning the detritus for use by detritivorous fauna. In fact, recent studies have suggested that the associated microflora may be the actual food source of the detritivores (Mann, 1972a,b; Brown and Sibert, 1977; McIntyre, 1969; Seki, 1966).

A simplified example of a shallow subtidal marine food web characteristic of Puget Sound, with an energy flow based principally upon detritus, is illustrated in Figure 4.

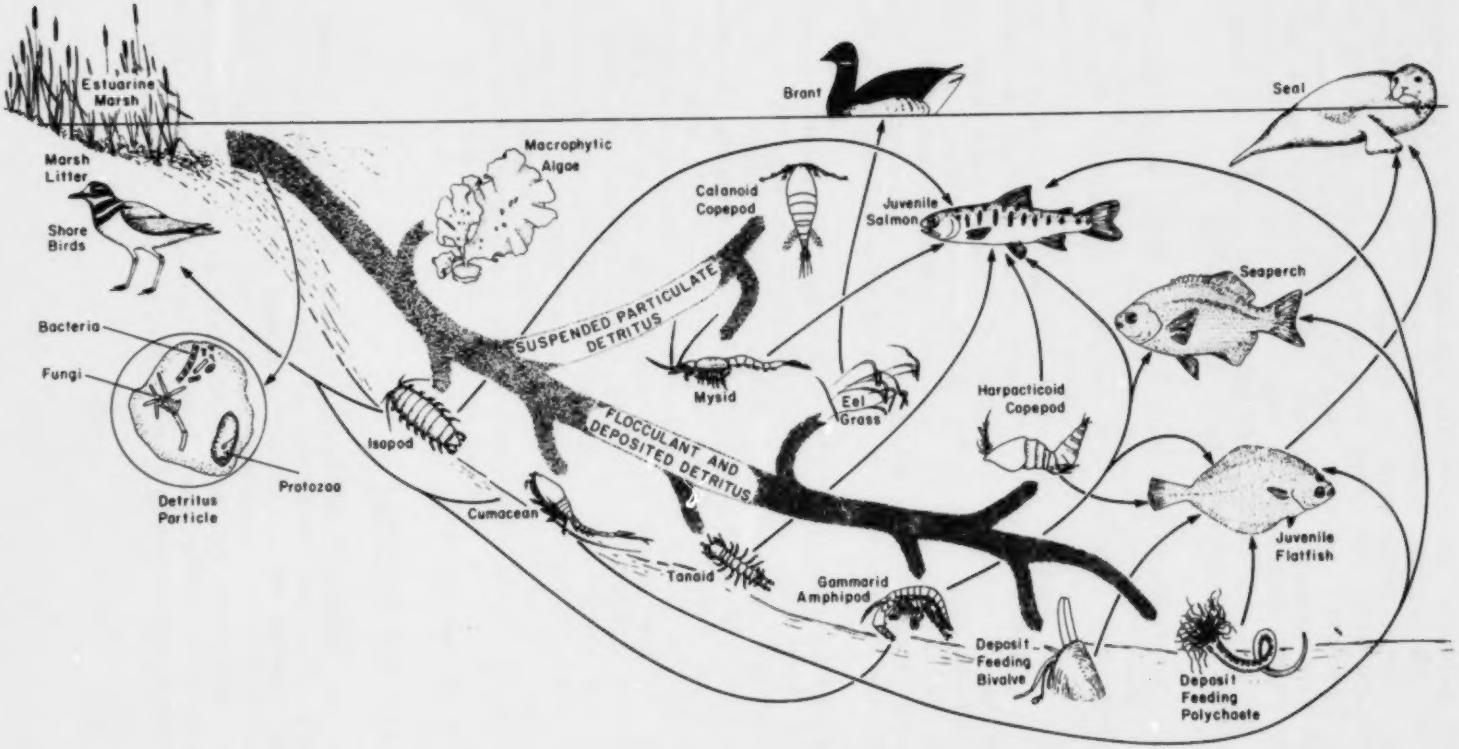

Estuarine Marsh
Marsh Litter
Shore Birds
Bacteria
Fungi
Protozoa
Detritus Particle
Isopod
Macrophytic Algae
SUSPENDED PARTICULATE DETRITUS
FLOCCULANT AND DEPOSITED DETRITUS
Cumacean
Tanaid
Calanoid Copepod
Mysid
Eel Grass
Brant
Juvenile Salmon
Harpacticoid Copepod
Gammarid Amphipod
Deposit Feeding Bivalve
Seaperch
Juvenile Flatfish
Deposit Feeding Polychaete
Seal

Figure 4. Simplified example of a detritus-based shallow subtidal food web.

III. D. Community Stability

A persistent question has been the existence of a relationship between the complexity of biological communities or their food webs and their "stability"--i.e., their resistance to collapse into a different, usually less diverse, structure in the event of a perturbation involving the removal of prey-predator linkages. Complex food webs are usually those having many species and many prey-predator linkages. Another question is whether food webs are actually "unstructured," in which case consumers randomly utilize energy from the pool of available, catchable prey species in trophic levels above that of primary production (Isaacs, 1972, 1973).

Considerable disagreement continues between those scientists who accept the established theory of increasing stability with increasing food web diversity and those who believe that randomly connected systems tend to become less stable as the connectance (number of linkages) increases. There are very few empirical data derived from laboratory or field studies where the relationship of food web structure and perturbations has been tested. The closest example of experiments directed toward these ends is that of Paine's (1966) manipulation of rocky shore communities of Washington's exposed coast in which removal of certain community dominants and their associated food web linkages was found to result in dramatic alterations (changed diversity and connectance) of the community and food web structure.

Thus, relatively complex food webs cannot be considered any more stable than less diverse food webs if removal of ecologically important taxa or trophic groups can have an identical restructuring effect. (Ecologically important species are those that are critical in maintaining the structure of a community.) Those species which are ecologically important either: (1) provide the majority of the energy sources for consumer organisms at some time; (2) provide unique processes of converting or transferring organic matter to states or trophic levels in which it is available to other consumers; or (3) are "keystones" in the composition of the community and in the direction and rate of food web energy flow, typically through selective predation or grazing. In all cases, these organisms are responsible for what might be considered "critical linkages" in the unperturbed food web, and the structure of the community is predicated upon their presence in sufficient numbers to exert a keystone effect.

III. E. Reproduction and Dispersal

Reproduction and dispersal patterns of individual species can have an important influence upon the structure of biological communities. Factors such as fecundity (number of offspring produced per individual), timing of reproduction, availabilty of breeding areas, and ability and tendency of young to disperse themselves can be as important as trophic relationships in determining the ways that communities respond to disturbances. Reproductive and dispersal patterns differ among biotic groups.

III. E. 1. Marine Mammals. Of the nine marine mammal species considered common in the study area, only three species (river otter, harbor seal, and killer whale) have been observed breeding here, although two other cetaceans may (harbor porpoise and minke whale). River otters and harbor seals give birth to their pups primarily on land, while killer whales give birth in the water. Pupping occurs annually in the spring and early summer for river otters and mid-summer for harbor seals. A female killer whale may give birth only once every three to four years. Pupping in river otters and harbor seals is limited to specific sites, generally on undisturbed small islands, making their regional reproductive success vulnerable to perturbation.

The dispersal ability of marine mammals as adults is excellent because of their tremendous mobility. Many of the species found here occur along the entire coast of North America; some have a worldwide distribution.

III. E. 2. Marine Birds. Twelve species of marine birds out of the approximately 80 species regularly reported breed in this region. All breeding species nest every year in the spring. Generally, nesting is localized, site-specific, and on small islands or other remote areas free of human and other mammal disturbance. Ninety-four percent of the approximately 30,000 regional breeding pairs nest on a group of islands off Lopez Island and on Smith/Minor, Protection, and Tatoosh Islands.

The dispersal ability of marine birds in most cases is superb because of their flying ability. The young birds of the year may wander far from their hatching site. The instigation of breeding is usually delayed for two or more years, varying among the species. From what little is actually known, site attachment varies from very strong to weak among both experienced adults and birds returning to their natal colony to breed for the first time.

III. E. 3. Marine Fish. Most marine fish of this region disperse eggs into the water during spawning. Some species spawn on intertidal beaches or deposit eggs among marine vegetation. Some members of the family Embiotocidae (sea perches) and a few other species develop eggs internally and release their young as fry. Eggs of most species remain near the bottom with the major exception of members of the family Pleuronectidae (flounders), in which the eggs drift near the surface. Larvae of virtually all species are small and planktonic. Except for members of the genus Hexagrammos (greenlings) in which larvae drift near the surface, fish larvae are distributed throughout the water column.

Marine fish here reproduce generally once a year in the late winter and early spring. Spawning and egg brooding in species which guard eggs are often localized and habitat specific. Herring spawning, for example, is restricted to intertidal cobble beaches. Reproduction success varies tremendously from year to year among those commercial species studied by fisheries biologists.

Unlike marine mammals and birds which disperse only as adults, or young-of-the-year, marine fish have excellent dispersal ability both as adults and larvae. Eggs and larvae may drift considerable distances before metamorphosis and maturation take place. All species have strong swimming capabilities and wide geographic ranges.

III. E. 4. Marine Benthos. Among the benthic plants and animals of this region, the method of reproduction varies across the entire spectrum known to biologists: asexual, sexual, haploid/diploid phases, direct development, or complex life histories with several larval phases.

Benthic organisms reproduce at least once each year and reproduction in most is strongly seasonal, usually peaking in late winter to early spring. In general, reproduction occurs where he adults are found, not in different, specialized breeding areas. Reproduction success among some benthic organisms in this region is known to occur in multi-year cycles and, thus, can be highly unpredictable.

While planktonic invertebrates have a high dispersal ability as larvae and adults, virtually all adult benthic organisms have very limited or no dispersal ability. For many of them reproduction involving a planktonic larval stage is critical for dispersal and recruitment to new areas. Despite the importance of planktonic larvae for dispersal, a planktonic larval stage is not universal among benthic organisms. Many produce eggs which develop into benthic or epibenthic larval or juvenile forms. Nonplanktonic life cycles are almost universal among small benthic crustaceans, nematodes, flatworms, and oligochaetes. They are very common among polychaetes and occur even among some bivalves, gastropods, sea stars, and sea cucumbers.

III. F. Migrations and Movements

In normal use, the word migration simply means to move from one place to another. When applied to animals, it has a special meaning: a migration is a repeated movement with the seasons, and implies a "once-a-year" periodicity. The most obvious examples of migrants are provided by birds. Birds have been classified and reclassified as to types of migratory movement. Unfortunately, many of these schemes are too rigid to apply to mammals and fish. Small fish may be carried passively hundreds of miles by oceanic currents and what may be no more than a dispersal could then have all the appearance of a true migration. The relative importance of active migration versus passive transport has been difficult to assess among fish.

The definition of migration as a class of movement which impels migrants to return to the region from which they have migrated is used here. Note that no distinction is made between active and passive migrations. The word "impel" is used in the sense of biological necessity. The more spectacular migrations are usually for feeding or spawning purposes, although another reason might be to secure more suitable climatic conditions.

III. F. 1. Marine Mammals. The term migration as it applies to marine mammals (and many terrestrial mammals as well), refers to long distance movements of a specific population or major segments of a specific population (often differentiated by age-class or sex), usually in response to specific biological or environmental factors. Availability of food resources and, secondarily, breeding areas, appear to be major factors which induce migrations (e.g., gray whales). Shorter, "local" movements of animals from one feeding area to another nearby or from nonbreeding to breeding areas are generally not considered migrations (e.g., killer whales in Puget Sound). Both of these generalized movements have been documented in the study area for certain species of marine mammals.

Cetaceans (whales, porpoises, and dolphins) are observed in northern Puget Sound most frequently in the spring and summer months. The reduced frequency of observations in fall and winter months suggests there are seasonal movements to and from the area. The extent of these movements and the numbers of animals involved are poorly known. It would be premature at this time to consider most cetaceans as being migratory through the study area. The biases within the existing data (generally greatly reduced censusing effort in winter months) make it difficult to know what these movements represent (Everitt et al., 1980).

The migratory behavior of the gray whale, which passes through Washington coastal waters, are well-known. Essentially the entire population of 11,000-15,000 animals passes through Washington coastal waters southbound to breeding areas in Baja California, Mexico in November and December and northbound to feeding areas in the Bering and Chukchi Seas from February to April. Occasionally, individuals or small groups of animals wander into the Strait of Juan de Fuca and Puget Sound during these migration periods.

The natural history of the pinnipeds (seals and sea lions) frequenting the study area is better understood than that of cetaceans. Thus, seasonal movements are easier to detect. The most abundant marine mammal in the study area, the Pacific harbor seal, is essentially nonmigratory. The California sea lion and northern sea lion are seasonal migrants with individuals of both species appearing in the study area in the fall following the breeding season and leaving the area by late spring. Two other pinnipeds, the northern elephant seal and northern fur seal, occur rarely in the study area during offshore movements in the spring and fall.

It is presumed that the greatest species diversity of marine mammals occurs in spring-summer with greatest abundance in mid- to late summer. This influx of animals most probably is in response to increasing abundance and diversity of suitable prey throughout the study area.

III. F. 2. Marine Birds. The term migration in reference to marine birds generally means the movement of birds over large geographical areas, i.e., the North American continent, the Western Hemisphere, the Pacific Coast of North America, or the North Pacific Ocean. Migration is a twice-annual event, with one movement in the spring from wintering areas to breeding grounds, and the other in the fall, when birds move from breeding areas to wintering areas. In some species there is essentially no migration, with adults and young staying relatively close to the nesting area, but this is not common.

The rate at which migration occurs is variable between species, and varies in date from year to year. Adults in some species migrate before young birds are ready to leave nest areas. Some species move slowly, with one or more stop-over areas in which they forage or may even molt, before continuing on the migration. Other species fly nonstop for tremendous distances, often without feeding or stopping.

Large-scale migrations occur in the study area, though actual migratory movements are not often readily apparent but are chiefly evidenced by presence/absence patterns which may change overnight or within a few days. Imbedded within these large-scale movements are other movements, often of major local proportions, i.e., movements from one feeding area to another, movements from night roosting to daytime foraging areas.

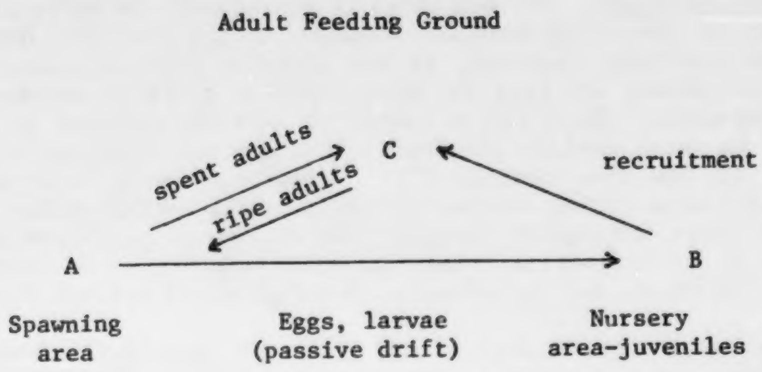
Many of the birds that breed in the study area appear to spend the winter in the area. Dispersal by young birds from a breeding colony may be rapid and extensive, while adults may move more slowly and for short distances; e.g., many immature Glaucous-winged Gulls appear to leave the area, while locally-nesting adults may not. Perhaps because of the mild winter in the study area and adequate food supplies most individuals of most breeding species appear to remain in the inland marine waters. However, the vast majority of the Rhinoceros Auklets leave the area for the winter, as do the Tufted Puffins.

The Puget Sound region (and the study area in particular) is very important as a wintering area and stop-over area for many birds migrating along the Pacific Coast. There are many species that stop here, with many individuals remaining for the winter while others continue south. This is the case with the Black Brant, with some staying here in a few locations all winter while most of the population continues south to winter in California and Mexico.

There are only a few species (e.g., a number of shorebirds) that appear here only as migrants on their twice-annual passages through the area. These species are generally long-distance migrants, some breeding on the Arctic slope and wintering in southern South America.

There are no species which have populations wintering exclusively within the study area. however, there may be currently unrecognized subpopulations that do reside here exclusively during the winter. There is evidence of individually marked birds (leg- or neck-banded waterfowl) or birds of rare species (presumably the same individuals) wintering at the same location over several years. It is also probable that individual long-lived marine birds or populations retrace their migration routes quite closely each year.

III. F. 3. Marine Fish. The research conducted in the study area indicates that fish migrations can usually be reduced to a simple triangular pattern:



A → B is with the water currents

B → C, and C → A are against the currents

A → C is with the currents

Some biologists theorize that the most abundant fishes (which are generally the commercially important fishes) are nearly always migratory fishes because of the evolutionary necessity of separating the three major life history stages (eggs/larvae, juveniles, adults) to provide maximum numbers.

There are many kinds of migrations and movements of marine fish in the study area which must be taken into account when considering the importance of various habitats. Three examples will be given to support this statement.

Juvenile pink and chum salmon, migrating from freshwater streams and rivers to the ocean, spend much of the first six months of the year (usually the spring and summer) along the beaches and shorelines feeding on epibenthic organisms. Although these are "transient species," they are present every year at approximately the same time.

Pacific herring spawn in the same marine areas year after year and on similar dates. Some of these areas, such as some of the ones classified as cobble and gravel habitats of low productivity, obviously present ideal conditions for both egg and early larval survival; there is little dispute among the scientists studying the early life history of fish that the key to larval survival is an abundant availability of the right kinds and densities of food.

Lingcod make annual spawning migrations from deep water to the nearshore waters of the rocky reef habitat. This migration occurs from about December through May and although the female spends little time in the shallow water once her eggs are deposited, the male guards one or more nests and may spend many weeks in the upper subtidal rocky habitat. Removal or abandonment of nests by male lingcod, for whatever reason, will usually result in the destruction of these nests.

III. G. Natural Stresses. As described in the section on Biogeography, the flora and fauna of the study area are similar to that of the larger North Eastern Pacific province. However, as one proceeds into the study area from the mouth of the Strait of Juan de Fuca, species richness decreases among benthic invertebrates. There are a number of natural stresses in the study area that may, in part, explain the decrease in species richness in the study area compared to the open coast. These natural stresses also affect how marine biological communities respond to human-caused perturbations. In some cases they may cause biological changes that exceed in magnitude those that may be caused by pollutants or other perturbations. Species richness for fish and birds increases due to increased protection and habitat diversity.

As one proceeds eastward through the Strait of Juan de Fuca and into the San Juan Islands, the mean wave energy decreases. Those species adapted to more exposed conditions, particularly those living in the intertidal zone, are not always replaced by species more adapted to quiet water; therefore, species richness is decreased.

Exposure of intertidal habitats during tidal cycles has a profound effect on the distribution of organisms. In all habitats the strata submerged only during high tides are virtually barren of organisms. Species richness, total abundance and biomass usually increase in the lower tidal strata. Regional differences in the extent of stress from tidal exposure occur. The time of lowest tide in spring and summer near the Pacific Coast is in the early morning, while in fall and winter the lowest tides are in midday. More easterly in the study area (i.e., the San Juan Islands), the timing of maximum exposure is reversed. Spring and summer lowest tides are in midday or early afternoon, and winter time lowest tides are during the night. This means that the intertidal area in summer is exposed to maximum insolation and exposure stress and in winter is exposed to lowest temperature and the greatest risk of freezing. The effect of intense summer insolation is evident in the "summer burn off" of algae. In rock and cobble habitats relatively rich growths of brown and green algae that can be found in the lower intertidal in March and April are very much reduced in July and August.

Although estuaries are rich and productive areas in their own right, the reduced salinity caused by river flow is a stress to many organisms and species richness can be relatively low. Small localized estuaries are found throughout the study area (i.e., Pysht River, Elwha River). The Fraser River discharges the greatest amount of freshwater to the study area. Depressed salinity in the freshwater/seawater mixing zone is a stress to many species adapted to more saline conditions. Smaller scale lower-salinity stresses may occur where groundwater seepage, springs, small creeks, and storm drains occur. As a result of reduced salinity, some species normally occurring in the area may be missing from communities located near the source. They may or may not be replaced by other species more tolerant of low salinity.

Uprooted trees and cut logs commonly occur in the study area and can be a stress to intertidal biota. Particularly during storms, logs scour the intertidal areas and may cause extensive damage, particularly, to rock and cobble habitats. This "natural" stress is even more pronounced on the open coast and has been documented by Dayton (1971). Log scouring may create new space for colonization by removal of existing biota. It also may increase the diversity of habitat types by modifying the substrate type. The magnitude of effects varies with the amount of wave action.

IV. BIOLOGICAL CHARACTERIZATION OF MAJOR HABITAT TYPES OF NORTHERN PUGET SOUND AND THE STRAIT OF JUAN DE FUCA

IV. A. Intertidal/Subtidal

IV. A. 1. Habitat definitions. In designing a sampling program for marine communities, with the exception of mammals and to some extent birds, it is not possible to sample the entire biota of a region. An alternative approach is to use a habitat-by-habitat sampling design. Therefore, using this design, the range of habitats within the study area was first determined and then typical areas representative of each type were selected for sampling. The bird and mammal censuses were conducted areawide and the habitat types noted for each standard subregion. A number of classifications of the nearshore habitat of this region have been developed recently by various state and federal agencies. In reviewing these and the data gathered to date on the biological communities of the region, the range of habitats was divided into three major types labeled according to sediment type and exposure to wave action and tidal currents. These are:

(1) exposed unconsolidated sediments (coarse sand and gravel),

(2) protected unconsolidated sediments (mud and mud mixtures), and

(3) rock (including cobble).

Several points must be kept in mind with regard to intertidal/subtidal habitat designations. First, both exposure and sediment types are physical characters with continuous gradients, not a series of discrete states. The communities characteristic of each habitat type are also present in continuous gradients, not in discrete states implied by these treatments in a classification scheme. Another important point to keep in mind is that the habitat found in the intertidal zone at a given site may not be the same as that in the subtidal zone. Generally, sampling or direct observation is necessary to determine the subtidal habitat type.

IV. A. 1. a. Exposed unconsolidated sediments. This habitat type (Figure 5) is defined by its exposure to moderate-to-severe wave and/or tidal current action. This severity of exposure precludes the accumulation of fine sediments, so the substrate ranges from sand to gravel to small cobble. The sediments are not stable. They are either in constant motion or in motion during severe wave or current conditions. This motion is sufficient to preclude the development of a surface community of attached macroscopic organisms. This absence of live organisms and more generally even the absence of evidence of organisms such as tubes, casts, or shells is a diagnostic surface feature. The beach gradient or slope is steep; therefore, the beach is narrow. The backshore is usually limited in development. The beach geomorphology is erosional, often associated with feeder bluffs and longshore sediment movements.

Within this general habitat type two subcategories are recognized, based largely on sediment type. The first is defined by exposed mixed coarse sediment, primarily gravel and small cobble with little or no sand. The sediment is in constant motion but the large between-grain pore size may provide refuge space for some small organisms, including meiofauna. This sediment motion also functions as a grinding mill, reducing the particle size of trapped detritus. The other subcategory of exposed unconsolidated sediments is exposed sand, primarily medium to coarse. This sediment is somewhat more stable than that described above and the slope less steep. The pore or interstitial space is much more restricted, and it usually occurs in areas slightly less exposed than those with mixed coarse.

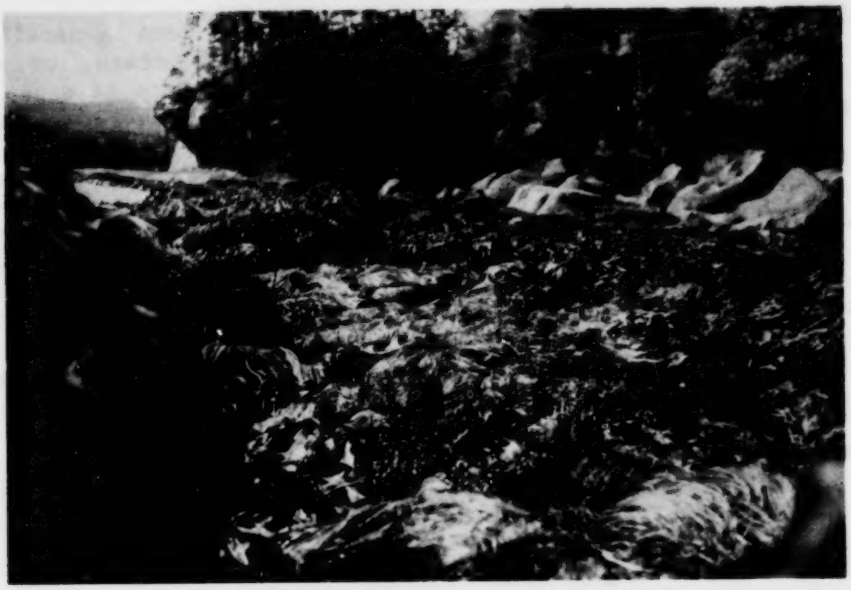
IV. A. 1. b. Protected unconsolidated sediments. The overriding characteristic of this habitat type (Figure 5) is the protection from strong wave and/or tidal current action. This is the habitat of the bays and harbors of this region. Protection from waves allows for the accumulation of fine sediment, mud, and silt, often mixed with some sand and gravel. The beach surface and sediments are stable. The diagnostic surface feature of this habitat type is the presence of abundant live organisms, their holes, casts, and tubes.

The beach gradient is low and the width is relatively great. The backshore is often very well-developed and occasionally associated with marshes. The geomorphology of these beaches is accretional; the sources of fine sediment are rivers, streams, or erosional bluffs.

Within this major habitat category the subcategories of protected gravel/mud, sand/mud, and mud may be recognized by their dominant sediment type, reflecting the influence of increasing percent mud. Pore size decreases, retention of organic debris increases, and the degree of protection increases as grain size decreases from gravel/mud to mud.

IV. A. 1. c. Rock. The exception to continuous gradients of sediment substrata discussed above is the discrete substrate of rock. The diagnostic feature of this habitat type (Figure 6) is the presence of the solid rock surface. This surface provides a stable substrate for organisms which can attach to it (epifauna and epiflora) regardless of the severity of exposure to tidal current and wave action. Therefore, exposure in the habitat type covers the range from protected to extremely exposed. The beach slope of rock habitats varies from medium to steep, although some areas are characterized by a fairly broad wave-cut terrace.

Three subcategories of this major habitat are recognized. The first two are characterized by the presence of solid rock and represent the extremes of the wave exposure gradient: protected rock and exposed rock. The third

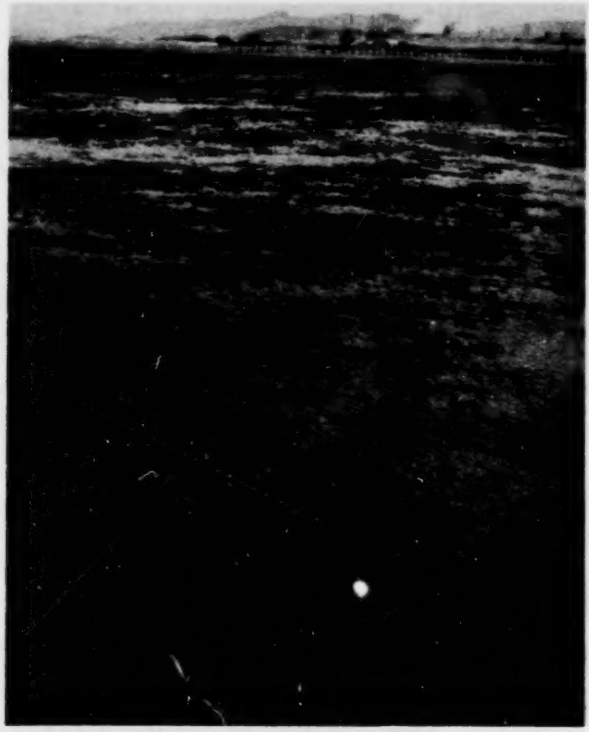


a. Rock habitat

b. Cobble habitat

Figure 6. Examples of intertidal rock and cobble habitat categories.

a. Exposed unconsolidated habitat



b. Protected unconsolidated habitat

Figure 5. Examples of exposed and protected unconsolidated intertidal/subtidal habitat categories.

subcategory is more complex: the cobble habitat (Figure 6). This habitat is characteristic of erosional beaches where the eroded material contains large cobbles, resistant to movement by wave or tidal action, that cover a wave-cut terrace and allow the accumulation of finer sediments under the rocks. This subcategory is a hybrid between the rock habitat and the protected unconsolidated habitat in that it supports both an infaunal and an epifaunal biotic component. Because of the heterogeneous character of the cobble habitat, it is considered by many to be a unique and distinguishable habitat category. However, in this report it will be considered as a subcategory of "rock," reflecting the strong influence of the epibiota in the composition of the community associated with it.

IV. A. 2. Spatial extent. Rough estimates of the distribution of the three major habitat types are shown in Figure 7. These estimates were based upon shoreline type designations provided in the Washington Coastal Zone Atlases.

Exposed unconsolidated habitats occupy about 50% of the shoreline. This habitat type is common along the eastern portion of the Strait; the west coast of Whidbey Island; around parts of Lopez, Guemes, and Lummi Islands; and along parts of the shore extending between Sandy Point and Boundary Bay.

Rock (and cobble) occupy about 40% of the shoreline. Major rock areas occur along the western portion of the Strait and around many parts of Orcas, San Juan, Shaw, and Stuart Islands.

The remaining shoreline (about 10%) is occupied by protected unconsolidated sediments. This habitat type is restricted to embayments such as Discovery, Dungeness, Padilla, Samish, Birch Bays, and Drayton Harbor. Very little protected unconsolidated habitat occurs along the Strait and in the San Juan Islands.

IV. A. 3. Major biological assemblages. Study sites at which intertidal/subtidal data were collected are listed in Table 1 along with the habitat type that each site represented. The locations of these sites and the geographic extent of the data base are shown in Appendix Figures I-A through I-D. The following discussions were derived from syntheses of data collected at these sites. Individual data sets were archived in technical reports and on magnetic tapes (Appendix Table I-A). The tape formats are listed in Appendix Table I-B.

IV. A. 3. a. Dominant and characteristic species of intertidal/shallow subtidal benthic habitats.

IV. A. 3. a. (1) Rock/cobble habitat.

Marine mammals: Harbor seals were the most important marine mammals to use this habitat type, followed by the sea lions (northern and California) (Appendix Table II-A). This habitat was very important at low tide for haul out, resting, breeding, and pupping for harbor seals. All the important rock haul-out sites were located on islands (Table 2), thereby affording these animals some protection and isolation from human disturbance. The rock habitat was used by 68% of the local harbor seal population during the period

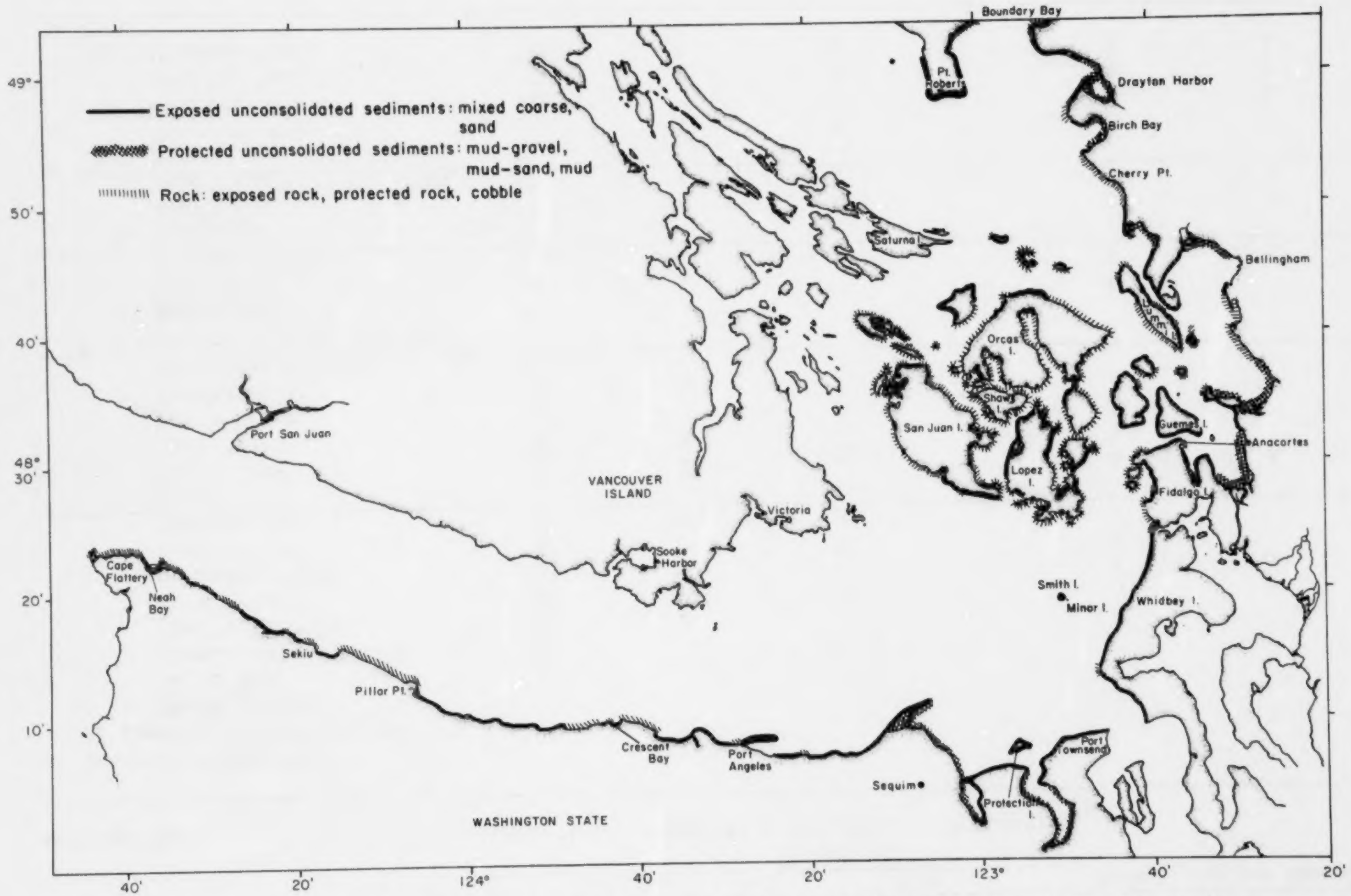

Exposed unconsolidated sediments: mixed coarse, sand
Protected unconsolidated sediments: mud-gravel, mud-sand, mud
Rock: exposed rock, protected rock, cobble
Boundary Bay
Pt. Roberts
Drayton Harbor
Birch Bay
Cherry Pt.
Saturna I.
Bellingham
Lummi
Orcas I.
Shaw I.
San Juan I.
Lopez I.
Guemes I.
Anacortes
Fidalgo I.
Port San Juan
VANCOUVER ISLAND
Victoria
Sooke Harbor
Cape Flattery
Neah Bay
Sekiu
Pillar Pt.
Crescent Bay
Port Angeles
Sequim
Protection I.
Port Townsend
Smith I.
Minor I.
Whidbey I.
WASHINGTON STATE
49°
50'
40'
48° 30'
20'
10'
40'
20'
124°
40'
20'
123°
40'
20'

Figure 7. Estimated spatial extent of major intertidal/subtidal habitat types in the study area.

Table 1. Intertidal/subtidal, nearshore and offshore study sites per habitat type.

Habitat/Site	Benthos		Fish		Birds*	Marine Mammals
	Intertidal	Subtidal	Intertidal/ Subtidal	Nearshore		
A. Intertidal/subtidal						
1. Exposed unconsolidated						
a. Mixed coarse						
Legoe Bay	X		X		A	
Guemes Island South	X		X			
Ebey's Landing	X	X			X	
Twin Rivers	X	X	X		A	A
Dungeness Spit	X	X	X		X	A
South Beach	X	X	X		X	
Deadman Bay	X	X	X		A	
b. Sand						
Eagle Cove	X	X	X		A	A
West Beach	X	X	X		S	
North Beach	X		X		A	
Kydaka Beach	X	X	X		A	A
Alexander's Beach			X			
2. Protected unconsolidated						
a. Mud-gravel						
Webb Camp	X	X			B	
Beckett Point	X	X	X		X	A
b. Mud-sand						
Birch Bay	X	X	X		S	A
Jamestown/Port Williams	X	X	X		X	A
c. Mud						
Westcott Bay	X	X	X		B	
Drayton Harbor	X		X		S	A
Padilla Bay	X		X		X	A
Fidalgo Bay	X	X	X		S	A

Continued

Table 1. (Contd.)

Habitat/Site	Benthos		Fish		Birds*	Marine Mammals
	Intertidal	Subtidal	Intertidal/ Subtidal	Nearshore		
3. Rock/cobble						
a. Exposed rock						
Neah Bay			X		X	A
Slip Point			X		A	A
Pillar Point	X	X			A	A
Tongue Point	X	X	X		A	A
Observatory Point			X		A	A
b. Protected rock						
Migley Point	X				A	A
Fidalgo Head	X	X			X	A
Cantilever Pier	X					
Barnes Island			X		X	A
Point George		X	X			
Allan Island			X		B	A
c. Cobble						
Cherry Point	X	X	X		X	A
Shannon Point	X				X	
Partridge Point	X	X			X	A
North Beach	X	X	X		A	
Morse Creek	X	X	X		X	A
B. Nearshore (Neritic)						
1. Exposed						
Kydaka Beach				X	A	A
Twin Rivers				X	A	A
Pillar Point				X	A	A
Morse Creek				X	A	A
Dungeness Spit				X	X	A

Continued

Table 1. (Contd.)

Habitat/Site	Benthos		Fish		Birds*	Marine Mammals
	Intertidal	Subtidal	Intertidal/ Subtidal	Nearshore		
B. 1. Exposed (Contd.)						
Jamestown/Port Williams				X	X	A
Beckett Point				X	X	A
West Beach				X	X	A
Alexander's Beach				X		
South Beach				X	X	
Deadman Bay				X	A	
Eagle Cove				X	A	
Burrows Island				X	B	A
2. Protected						
Birch Bay				X	S	
Cherry Point				X	X	A
Lummi Bay				X	S	
Migley Point				X	A	A
Legoe Bay				X	A	A
Guemes Island East				X	B	
Padilla Bay				X	X	A
Guemes Island South				X		A
Shannon Point				X	X	A
Point George				X		
Westcott Bay				X	B	
C. Offshore						
1. Bays					X	A
2. Broad Passages					X	A
3. Narrow Passages					X	A
4. Open Waters					X	A

*X indicates sites where multiple bird censusing methods were used; A indicates aerial censuses only; B indicates boat surveys only; S indicates shore censuses only.

Table 2. Major haul-out areas of pinnipeds in the study area

Site	General Location	Habitat Type
Harbor seals		
Sentinel Island	San Juan Islands	Rock
Ripple Island	San Juan Islands	Rock
Cactus Island	San Juan Islands	Rock
White Rock	San Juan Islands	Rock
Skipjack Island	San Juan Islands	Rock
Bare Island	San Juan Islands	Rock
Sucia Island	San Juan Islands	Rock
Matia Island	San Juan Islands	Rock
Puffin Island	San Juan Islands	Rock
Peapod Rock	San Juan Islands	Rock
Bird Rock	San Juan Islands	Rock
Buck Island	San Juan Islands	Rock
Barnes Island	San Juan Islands	Rock
Dinner Island	San Juan Islands	Rock
Smith-Minor Islands	Eastern Strait	Cobble, gravel
Protection Island	Eastern Strait	Cobble, gravel
Dungeness Spit	Eastern Strait	Exposed unconsolidated
Dungeness Bay	Eastern Strait	Protected unconsolidated
Race Rocks	Eastern Strait	Rock
Chain Islets	Eastern Strait	Rock
Becher Bay	Eastern Strait	Rock
Padilla Bay	North Sound	Protected unconsolidated
Samish Bay	North Sound	Protected unconsolidated
Bellingham Bay	North Sound	Protected unconsolidated
Sea Lions		
Race Rocks	Eastern Strait	Rock
Sombrio Point	Eastern Strait	Rock
Port Gardner*	Eastern Strait	Protected unconsolidated
Tatoosh Island	Western Strait	Rock

*Outside main study area, sea lions haul out on grounded barge.

of peak abundance (August) and by all sea lions. Race Rocks and Sucia Island were highly important rock sites for harbor seals. Race Rocks was also the most important rock site for sea lions. River otters are known to forage in rocky intertidal/shallow subtidal areas.

Birds: The most common groups of birds observed at rock/cobble sites were gulls, shorebirds, and ducks (Appendix Table II-B). Many species are migrants or winter visitors. Glaucous-winged Gulls were observed in 100% of the surveys (Appendix Tables III-A-C). Surf scoters were very common, especially in the winter, occurring in up to 100% of the surveys. The other common species were Bonaparte's Gull, Harlequin Duck, Bufflehead, and White-winged Scoter (Appendix Table II-B).

While a number of birds (e.g., cormorants and gulls) are known to roost on rocks above normal tidal levels, very few species forage directly in the solid rock intertidal and shallow subtidal habitats themselves. The ubiquitous Glaucous-winged Gull accounts for much of roosting usage, and Great Blue Herons, Harlequin Ducks, and scavenging Bald Eagles along with small numbers of a few rock-foraging shorebird species represent almost all the foraging usage.

In general, the density of birds in rock/cobble habitats was usually much lower than in other habitats. Density and biomass varied greatly in locations where seasonal herring spawning attracted large numbers of some birds, particularly Surf Scoters and other diving ducks. Relatively few wading birds appear to use this habitat. This apparently is one of few habitats supporting nonbreeding populations of diving birds in summer.

Fish: About 18 species of fish were found in this habitat type, including sea perch, sculpin, and juvenile forms of various rockfish, flatfish, and cod. Some species were commonly found only in the tidepools of the rock/cobble habitat (high cockscomb, calico sculpin, mosshead sculpin, northern clingfish, and black prickleback) (Appendix Table II-C). Another species (the tidepool sculpin) was found commonly both in tidepools and at other habitats. Where Nereocystis luetkeana kelp beds were present in the shallow subtidal area, a group of fishes (including sea perch, rockfish, greenling, lingcod, sculpins, and gobies) was commonly found that was not found at other habitats.

Intertidal benthos: The dominant benthic species found at the rock and cobble habitats are listed in Appendix Table II-D. Some 83 taxa of algae and macroinvertebrates were dominant at the rock habitat, while about 81 were dominant at the cobble habitat. The primary producers include macro- and microalgae. The dominant macroalgae were distributed primarily in the mid- to low-tide zones (and were usually more extensive in the shallow subtidal area). They included species of 53 Alaria, Fucus, Microcladia, and Gigartina in the intertidal elevations and species of Desmarestia, Plocamium, Pterygophora, and Costaria in subtidal zones. Macroalgae were characterized by relatively large standing stock biomass and were not extensively used by herbivores. Microalgae (mostly benthic diatoms) were common in the mid- to high-tide areas.

When dominant, macroalgae were an important factor in community structure and relative abundance of other species at the rock/cobble habitats. Macroalgae can provide a three-dimensional component to the basic two-dimensional rocky surfaces. Similar to the trees of a forest, some macroalgae, such as *Laminaria*, *Egregia*, and *Alaria*, may be considered as canopy species. The "shading" created by the canopy species dissipates some of the energy of waves and thus provides some relief from exposure and encourages the growth of red algae species that find lower light intensity conditions optimal for growth. Where algae species such as *Alaria*, *Iridaea*, and *Polysiphonia* were important, tube building amphipods, such as *Ampithoe* sp. were also found. Algae such as *Corallina vancouveriensis* or *Endocladia muricata* can support large numbers of small mussels, small worms, and other wormlike species.

If barnacles predominate, species inhabiting crevices, such as *Typosyllis adamantea* and the nemertean *Emplectonema gracile* may be more abundant. Amphipod species, such as *Hyale* sp., which can nestle in crevices, are also more abundant. Thus, dominance has a functional as well as a descriptive aspect in these habitats.

The three-dimensional effect of macroalgae in the rock/cobble habitat was found to be most well-developed at sites in the western areas of the Strait. At cobble sites, the extent of the three-dimensional effect of algae was also related to cobble size; cobbles must be large enough to remain stationary.

A group of herbivorous urchins (*Strongylocentrotus franciscanus* and *S. droebachiensis*), snails (*Littorina sitkana*, *L. scutulata*, and *Collisella pelta*), and chitons (*Katharina tunicata* and *Cyanoplax dentiens*) were common intertidal animals but were not found as dominant species in subtidal areas. Although some herbivores (i.e., chitons) may eat macroalgae, most apparently rely upon the microalgae and sporlings of macroalgae as food. Herbivores were distributed throughout the intertidal zone and were the most commonly encountered large animals in the mid- to high-tide zones.

Predators common to the rock/cobble habitats include anemones, flatworms, polychaetes, nemerteans, snails, and seastars. Four predators that were not frequently sampled (because of patchiness and mobility) have an important impact on community structure of the rock/cobble habitat. These are the snails (e.g., *Fusitriton oregonensis*, *Nucella lamellosa*, and *N. emarginata*) and the seastars (e.g., *Pisaster ochraceus*, *Dermasterias imbricata*, *Solaster stimpsoni*, and *Leptasterias hexactis*.) Under optimal conditions, these snails can remove all of the juvenile barnacles and mussels that attach as larvae in any given year. The seastars may also dramatically affect community structure by preying upon barnacles, mussels, and snails.

Suspension feeders include barnacles, mussels, bivalves, and spirorbid polychaetes. Where large mussels were common (primarily in the western Strait), a three-dimensional effect (similar to that of the macroalgae) was found. Where fine sediments were trapped in mussel beds, suspension feeders (bivalves) and deposit/suspension feeders (polychaetes, crustaceans) were found.

At cobble sites, the spaces between the cobbles and the finer sediments that collect between and below the cobbles provided habitat for suspension and deposit feeders. In general, more species of suspension and detritus feeders were found at cobble sites compared with rock sites, possibly because of the greater habitat diversity.

Subtidal benthos: At most sites where rock or cobble were sampled in the intertidal zone, some different substrate was found in the subtidal area. Thus, the data base for subtidal benthos associated with rock and cobble is relatively weak. About 92 taxa were dominant in subtidal rock and cobble habitats (Appendix Table II-D). The shallow subtidal area of the rock/cobble habitat, in general, has similar functional characteristics to the intertidal area. However, the species are different and there are often more of them. Intertidal algae, such as *Fucus*, *Enteromorpha*, and *Porphyra*, were often replaced in the shallow subtidal zone by *Laminaria*, *Nereocystis*, and *Costaria*. Red algae were more common, often dominant, in subtidal areas than in intertidal areas. At exposed sites the eelgrass *Phyllospadix scouleri* was a dominant plant in the shallow subtidal. At some cobble sites, patches of the eelgrass *Zostera marina* species were common. However, this species was much more common in the protected unconsolidated habitats.

Herbivores at shallow subtidal areas were not as common as in the intertidal zone. On the other hand, suspension and deposit feeders (mostly bivalves and polychaetes) were more common at subtidal areas than intertidal.

IV. A. 3. a. (2) Exposed unconsolidated habitat.

Marine mammals: A number of small isolated areas, specifically Smith-Minor Islands, Protection Island, and Dungeness Spit, were found to be very important haul-out and pupping areas for harbor seals (Table 2, Appendix Table II-A). The largest single counts of harbor seals were made at these sites. Protection Island and Minor Island account for nearly 20% of the observed harbor seal population during the period of peak abundance (August).

Birds: The groups of birds using this habitat type included the gulls, terns, ducks, alcids, and shorebirds (Appendix Table II-B). Surf Scoters, White-winged Scoters, and Glaucous-winged Gulls were the most widespread and abundant species, followed by the Bufflehead, Mew Gull, and Bonaparte's Gull. Densities were higher in mixed coarse subtidal sites than in unconsolidated sand locations, and greatest seasonal use occurred in winter (Appendix Tables III-D and III-E). Censuses over these habitats also recorded high seasonal densities of several gulls. However, gulls often used locations like Dungeness Spit and West Beach as daytime roosts adjacent to offshore foraging areas; thus, these figures may not reflect biological productivity of the intertidal/subtidal habitats themselves. There was relatively low use of these habitats by shoreline foragers like shorebirds, probably reflecting low densities of prey species.

Fish: This habitat appears to support fewer fish species than any other habitat. About 36 dominant species were found, including sea perch, sculpins, flounders, gunnels, greenlings, and juveniles of the Pacific tomcod, cabezon, and English sole (Appendix Table II-C). Although there were relatively few demersal species found in the shallow subtidal and the intertidal zones, the habitat appears to be important to some neritic species. Gravel and sand beaches in the shallow subtidal zone are known to be used by some species for spawning (i.e., Pacific herring).

Few species occurred at exposed sand beaches and exposed gravel beaches; the least occurred at sandy sites. Where an exposed unconsolidated site was adjacent to another habitat type, the species composition of fish was affected. For example, the Twin Rivers site was gravel and sand in the shallow subtidal, but cobble and rock substrates border the beach seine site and the fish species were characteristic of these other habitats.

Sites with intertidal exposed unconsolidated habitat often had different sediments in the shallow subtidal area. Most of the shallow subtidal substrate at exposed unconsolidated sites had large cobbles with attached epiflora and fauna (i.e., Ebey's Landing, Guemes Island South, Legoe Bay). Many more fish species were often found at such sites. Many species of sea perch, gunnels, sculpins, poachers, and flatfish were dominant (including juveniles of Pacific tomcod, walleye pollock, copper rockfish, cabezon, and English sole). It is of interest to note that the fish fauna found at these exposed mixed coarse sites was very similar to the fish fauna of the protected unconsolidated habitat.

Intertidal benthos: Compared to other habitats, the intertidal flora and fauna at the exposed unconsolidated habitat was impoverished. Only 21 taxa were dominant at this habitat (Appendix Table II-D). Except for diatom films (not measured) and occasional bands of the green algae (Monostroma or Ulva) that may be found on patches of cobble in the low intertidal, no attached plants were dominant at this habitat. Only two herbivores--the amphipod Anisogammarus pugettensis and the snail Lacuna variegata--were dominants. Most remaining species were deposit feeders--polychaetes, amphipods, isopods, nematodes, oligochaetes, and bivalves. These species probably feed on detritus imported from other habitats. Compared to other habitats, polychaetes were poorly represented due to sediment instability and the relative lack of fine material in the sediment. Nemerteans were often the top carnivore found in this community.

There is generally a higher spatial variability in dominant forms at this habitat than in the others. Conditions of desiccation and substrate instability are often extreme. Colonization is usually difficult and patchiness of distribution is correspondingly large.

Although the general benthic biomass of this habitat was low, notable exceptions have been observed. Amphipods of the genus Paraphoxus and Paramoera were seasonally very numerous. For example, up to 40,000 Paramoera mohri per square meter were consistently found in the summer at Ebey's Landing.

Subtidal benthos: Only three sites with exposed unconsolidated sediments in the shallow subtidal area were sampled: Dungeness Spit, Twin Rivers, and West Beach (Appendix Table II-D). The substrate in the subtidal zone of the study area was more often cobble with high substrate stability.

Fine sediments often occurred between and under the cobbles. Ebey's Landing and Legoe Bay exemplified this habitat type and are discussed above.

At the sites with exposed unconsolidated substrate in the shallow subtidal area, the benthos often illustrate a pattern similar to that of the intertidal zone. That is, relatively few species were found as dominants. A total of only 14 species were dominant at Dungeness Spit and West Beach. None were primary producers. Deposit and suspension feeders were often less common than at other habitats, although there were more species in the subtidal areas than in the intertidal areas (probably related to increased protection and finer sediments in the subtidal substratum). The small bivalves *Mysella tumida* and *Psephidia lordi* were common as were sand dollars, *Dendraster excentricus*. More deposit feeding polychaetes were found in the subtidal compared to the intertidal zones. However, polychaetes were more numerous in the protected unconsolidated and rock/cobble habitats. It appears that substrate instability may prevent the occurrence of tube building polychaetes in the exposed unconsolidated habitat.

IV. A. 3. a. (3) Protected unconsolidated habitat.

Marine mammals: Mud and sandflats are used for haul-out by harbor seals, and apparently no other species (Appendix Table II-A). Sites observed to be important for haul-out included Padilla Bay, Samish Bay, Dungeness Bay, and Jamestown (Table 2). Some of these areas, for example Padilla Bay, were used for haul-out only at low tide when the mudflats were exposed. Drainage channels are often used for escape from disturbance. Though sea lions were observed in a muddy area of Port Gardner, they were hauled out on a barge.

Birds: Gulls, terns, ducks, geese, sandpipers, and grebes were found to be the dominant groups of birds in this habitat type (Appendix Table II-B). This habitat supported some of the highest seasonal densities and biomass of marine birds within the study area (Appendix Tables III-F-H). In addition to high numbers of the widely occurring diving ducks, eelgrass-associated species like Black Brant and wigeon formed very large components of the populations in winter and during migrations. Gulls also foraged in large numbers in these areas at low tidal stages.

The tables in Appendix III, representing the 10 most-frequently observed species in each season, do not reflect the great relative importance of these habitats to shorebird populations or the fact that seasonal species richness in these habitats was greater than other subtidal/intertidal habitat types.

Most usage of these habitats was by winter resident and migrant species. Breeding species generally do not nest adjacent to these habitats (except at Padilla Bay, Jamestown, and Drayton Harbor); i.e., nest sites are generally not available, so summer usage is relatively low. However, resident Glaucous-winged Gulls often forage in large numbers on exposed intertidal flats during the summer.

These protected unconsolidated habitats are also heavily used, particularly in summer, by Great Blue Herons. Several nesting colonies were located adjacent to protected embayments in the study area. The data in

Appendix III represent averages from censuses taken at all tidal stages and, since herons were not present at all during high tides, densities of this species were understated for areas near nesting colonies. For example, at Padilla Bay or Samish Bay 300± birds were observed foraging at low tides in summer.

Fish: Twenty-eight species were dominant at sites representing this habitat type: sculpins, the tube-snout, various sea perch and juvenile Pacific tomcod, English sole, and starry founders (Appendix Table II-C). The common fish fauna at this habitat was similar to that of sites where the shallow subtidal sediment was exposed mixed coarse. Beckett Point samples often had the most species, greatest density, and greatest biomass of any of the sites that were studied.

Intertidal benthos: The intertidal benthos of the protected unconsolidated habitat was generally more species-rich than the unconsolidated exposed habitat, and less species rich than the rock/cobble habitat. Some 75 dominant taxa of benthos were found at this habitat (Appendix Table II-D).

Most primary production was from eelgrass meadows of Zostera marina, although eelgrass meadows had their maximum abundance in the shallow subtidal depths. Eelgrass in the intertidal zone was restricted to the +3 foot tide height or lower. Where eelgrass meadows were found, a three-dimensional structure was added to the community and epifaunal species (particularly amphipods) were commonly found. Eelgrass appeared to be a very important habitat for epibenthic zooplankton.

Benthic herbivores were not common in the intertidal zone at this habitat. Platynereis bicanaliculata (a polychaete) was found in the infauna. Other herbivores (i.e., Littorina spp. and Lacuna sp.) were found only at those sites having a cobble-like substrate at higher tidal elevations or on eelgrass.

Polychaetes were very well-represented at the protected unconsolidated habitat. Some 30 dominant taxa were found in the intertidal areas. Most were deposit feeders, with some predators and a few suspension feeders. Bivalve molluscs were also well-represented at this habitat. Some 11 dominant species (primarily suspension feeders) were common at this habitat.

In protected habitats, predominant species can be divided into those which are numerically abundant, but which, because of their small size, have low biomass; and those which are not particularly numerous, but which contribute a major portion of the standing crop. The former category includes such groups as oligochaetes, small polychaetes, and amphipods; while large bivalves such as Macoma nasuta, Clinocardium nuttallii, Protothaca staminea, and Mya arenaria, and the mud shrimp, Upogebia pugettensis fall into the latter category. A few species were found to be important in both senses in some locations. These included the polychaetes Abarenicola sp. and Owenia fusiformis. The relative functional importance of species having high density but low collective biomass versus species having high collective biomass but low density is not clear, especially since information on rates of reproduction is lacking.

The upper tidal elevations of the protected unconsolidated habitat had a variable flora and fauna that were related to site specific substrate variations. Some sites (i.e., Birch Bay, Padilla Bay) had sandy or gravelly sediment in the upper intertidal zone and were found to have almost no flora or fauna. Other sites (Fidalgo Bay, Drayton Harbor) had cobble or rocky surfaces at higher intertidal elevations and had typical rock/cobble flora and fauna. At these sites, dominant epiflora and epifauna species included algae (Enteromorpha and Fucus), herbivorous snails (Littorina) and barnacles (Balanus glandula). At yet other sites (e.g., Westcott Bay) with protected unconsolidated habitat, marsh vegetation (not measured) was found beyond the upper intertidal elevations. At this site, bivalves (Mya arenaria, Macoma balthica), polychaetes (Abarenicola sp.), amphipods (Corophium spp., and tanaeids (Leptochelia dubia) were all commonly found at the +5 feet and +6 feet tidal elevations. Species richness and total abundance at these tidal elevations were greater at the high intertidal than at any other site in any habitat. At Westcott Bay, marsh vegetation continued from the +7 feet to +9 feet tide heights and beyond. Oligochaetes, nematodes, and dipteran larvae were found in this vegetation.

Subtidal benthos: Most taxa found in subtidal benthos were burrowing or tube-dwelling organisms. Few attached biota were found. Fewer dominant taxa of benthos (48) were found at the subtidal protected unconsolidated habitat compared to the intertidal (75 species). This trend is a reverse of that observed at most exposed unconsolidated and cobble habitats. Brown and red algae were occasionally found at this habitat, although the bulk of primary productivity occurred within eelgrass meadows.

Polychaete species were well-represented in the subtidal area of this habitat (24 dominant species) as well as in the intertidal zone (30 dominant species). Although most species in the subtidal area were deposit feeders (as in the intertidal zone), species composition differed between the subtidal and intertidal zones. Bivalve molluscs (suspension-feeders and carnivores) were common along with gammarid amphipods. Crabs seeking shelter among algal fronds and other debris were common.

IV. A. 3. b. Trophic organization.

IV. A. 3. b. (1) General background.

Trophic or food web structure of the biotic communities characterizing each broad habitat type have been described previously in Simenstad et al. (1979), where the relative importance of linkages between nodes (elements of the various trophic levels) were subjectively weighted by the occurrence of food items in the diet of the consumer. At that time no attempt was made to weight the relative importance of the producer or consumer in the community. A thorough evaluation of the organization and flow of organic matter through a food web, however, must consider the proportional production and utilization of organic carbon by the various components of the community. The availability of production and consumption rate information for organisms in this region is unfortunately too sparse and inconsistent to permit such a food web synthesis. As an alternative, though less than optimal, approach we have utilized the standing stock (the quantity of living material present per unit area at a selected point in time) of organisms in representative feeding categories to illustrate their relative role in the community.

While comparisons within trophic levels are feasible, standing stock estimates in different trophic levels should not be considered comparable nor used to imply energy flow due to the usually dramatic differences in production rates. That is, orders of magnitude differences exist in the generation times of phytoplankton versus herbivorous zooplankton versus zooplanktivorous fishes and birds. These differences are best illustrated by the production/biomass (P/B) ratio which has been shown by Petipa et al. (1970) to range in the Black Sea from 63 for primary producers, to 65 for herbivores, to 47 for primary carnivores, to 6 for secondary and tertiary carnivores in one epibenthic community. The implication from these data is the plants, because of their high turnover rate, produce much more organic matter than members of the higher trophic levels.

Even the standing stock data are incomplete in this region, especially for the lower trophic levels. Standing stock data for primary producers are the most limited. Macroalgae, sea grass, and saltmarsh plant standing crop values were obtained from averaging data from the WDOE and MESA intertidal/subtidal data sets over a year's sampling period. Although detritus was a food source of obvious importance, estimates of the proportional sources, rate of accumulation and standing stock of detrital carbon are nonexistent.

All other data on the standing stock of macroalgae, grazing herbivores, carnivores and other predators, omnivores and parasites originated directly from the WDOE and MESA intertidal/subtidal data sets, both published (Nyblade, 1977, 1978, 1979a/b; Smith and Webber, 1978; Webber, 1980; Smith, 1979; Everitt et al., 1979/1980; Manuwal et al., 1979; Miller et al., 1978/1980; Simenstad et al., 1977/1979/1980; Cross et al., 1978), and through further synthesis of these existing data. The taxonomic groups and species considered important below in the trophic organization of intertidal/subtidal habitats may not always agree with those considered important above in the community organization. The prey found in stomach content analyses were often dissimilar to the organisms found in benthos samples taken at the same sites.

IV. A. 3. b. (2) Rock-cobble habitats.

These habitats were characterized by high complexity and diversity in food web structures compared to other habitat types, including the offshore and nearshore neritic habitats. Detritus was found to be the most prominent source of organic carbon, based simply upon the number of food web linkages (Figure 8). Quantitative comparison of the standing stock of the four sources of organic detritus, microalgae, macroalgae, eelgrass, and phytoplankton, were not possible because the data only exist for two sources, the macroalgae and eelgrass. The macroalgae community was extremely diverse, including 24 prominent taxa in the intertidal zone and 31 taxa in the subtidal. Microalgae (mostly benthic diatoms) were most common in the upper

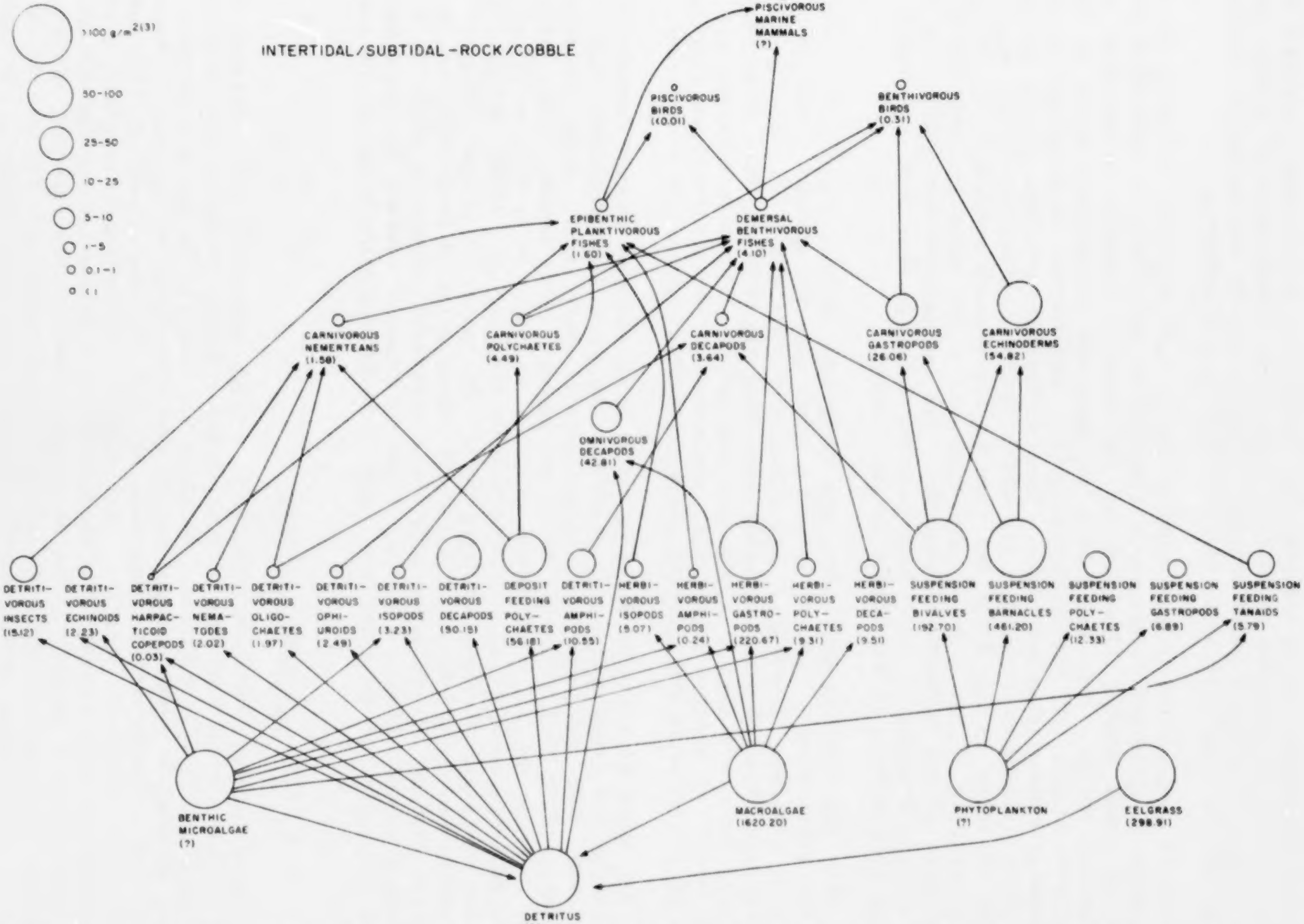

INTERTIDAL/SUBTIDAL-ROCK/COBBLE
>100 g/m$^{2(3)}$
50-100
25-50
10-25
5-10
1-5
0.1-1
< .1
PISCIVOROUS MARINE MAMMALS (?)
PISCIVOROUS BIRDS (0.01)
BENTHIVOROUS BIRDS (0.31)
EPIBENTHIC PLANKTIVOROUS FISHES (1.60)
DEMERSAL BENTHIVOROUS FISHES (4.10)
CARNIVOROUS NEMERTEANS (1.58)
CARNIVOROUS POLYCHAETES (4.49)
CARNIVOROUS DECAPODS (3.64)
CARNIVOROUS GASTROPODS (26.06)
CARNIVOROUS ECHINODERMS (54.82)
OMNIVOROUS DECAPODS (42.81)
DETRITIVOROUS INSECTS (15.12)
DETRITIVOROUS ECHINOIDS (2.23)
DETRITIVOROUS HARPACTICOID COPEPODS (0.03)
DETRITIVOROUS NEMATODES (2.02)
DETRITIVOROUS OLIGOCHAETES (1.97)
DETRITIVOROUS OPHIUROIDS (2.49)
DETRITIVOROUS ISOPODS (3.23)
DETRITIVOROUS DECAPODS (50.15)
DEPOSIT FEEDING POLYCHAETES (56.18)
DETRITIVOROUS AMPHIPODS (10.55)
HERBIVOROUS ISOPODS (5.07)
HERBIVOROUS AMPHIPODS (0.24)
HERBIVOROUS GASTROPODS (220.67)
HERBIVOROUS POLYCHAETES (9.31)
HERBIVOROUS DECAPODS (9.51)
SUSPENSION FEEDING BIVALVES (192.70)
SUSPENSION FEEDING BARNACLES (461.20)
SUSPENSION FEEDING POLYCHAETES (12.33)
SUSPENSION FEEDING GASTROPODS (6.89)
SUSPENSION FEEDING TANAIDS (5.79)
BENTHIC MICROALGAE (?)
MACROALGAE (1620.20)
PHYTOPLANKTON (?)
EELGRASS (298.91)
DETRITUS (?)

Figure 8. Characterization of rock/cobble intertidal/subtidal habitat food web. Average biomass of major taxa represented in parentheses(grams/m^2 or grams/m^3).

tidal zones where they were grazed upon by herbivorous amphipods, gastropods, and polychaetes.

Benthic infauna associated with sediments under and around cobbles and epibenthic primary consumers utilize three food sources (suspended matter, detritus, and attached plants) to some extent, with the suspension feeders illustrating the highest standing stock. Despite the high exposure and well-flushed habitat, detritus feeders are often numerous and suggest that the high relief of the substrate, with cracks, crevices and algae holdfasts, is conducive to the retention of large detritus particles in the sediments associated with cobbles. Polychaetes (including most often *Polydora pygidialis* and *Thelepus crispus*) and decapods (*Pagurus* spp.) were found to be the prevalent detritivores, with gammarid amphipods and insect (dipteran) larvae being secondary in importance among the 10 detritivore-feeding groups. Gastropods, chitons, and echinoderms made up about 90% of the standing crop of herbivores feeding upon macroalgae and microalgal scums. Barnacles (*Balanus* spp.) and bivalves (including *Mytilus* spp., *Saxidomus giganteus*, and *Clinocardium* spp.) dominated the suspension feeders, composing 68% and 28% of the total standing crop of that group, respectively.

Omnivorous decapods (*Hemigrapsus* spp.) utilized both detrital and macroalgal food sources.

The high standing stock of sessile suspension feeders was reflected in the secondary consumer level, which was characterized by high standing stocks of their predators, including echinoderms and gastropods. These two groups together comprised 89% of the total estimated standing stock at that trophic level. Polychaetes (*Pholoe minuta*), decapods (*Cancer oregonensis*), and nemerteans composed the remainder of the secondary consumers.

Among the tertiary consumers the demersal benthivorous fishes composed the highest proportion of the standing stock, primarily because they included two of the largest predators in the habitats' fish community, the kelp greenling (*Hexagrammos decagrammus*) and the lingcod (*Ophiodon elongatus*). Epibenthic planktivorous fishes, though composing a more diverse element of the community, accounted for less than one-half of the standing stock of the demersal fishes; yellowtail rockfish (*Sebastes flavidus*), black rockfish (*S. melanops*) and copper rockfish (*S. caurinus*) were the prominent species in this group.

The added dimension of the intertidal and shallow subtidal substrate also contributed to a greater diversity of birds foraging in these habitats. The benthivorous species, primarily the Surf Scoter, White-winged Scoters, and Glaucous-winged Gull, completely dominated this group.

The most important marine mammals to utilize prey resources within these habitats included the killer whale and Pacific harbor seal, though they likely forage primarily in nearshore and offshore waters. Both are opportunistic fish-eaters.

In general, this food web is broadly based upon a variety of carbon sources including detritus, although a greater proportion of the detritus generated by the extensive macroalgae production in these habitats is probably exported into other, more protected habitats. The major transfer of trophic energy, at least in terms of maintenance of standing stock of consumer organisms, however, is through macroalgae herbivores and suspension feeders.

IV. A. 3. b. (3) Exposed unconsolidated habitats.

The high exposure to waves and the unconsolidated character of coarse sediments typifying these habitats generally do not allow benthic vegetation to attach or persist to any degree. Thus, the majority of the autotrophic production from within the habitats is from phytoplankton production. The food web, however, is characteristically based upon detritus (Figure 9). It appears that spits, pocket beaches, and headlands exposed to heavy current and wave transport receive a relatively high biomass of detached macroalgae and other organic detritus from adjacent habitats. In these high-energy systems the large detritus particles are quickly broken down into smaller particles by the grinding action of the coarse sediments and are made available to the assortment of detritivores which are able to persist in the unconsolidated sediments. Among these detritus and general deposit feeders, the gammarid amphipods (especially Paramoera mohri and Paraphoxus spp.) comprised the highest proportion (83%) of the standing stock; echinoderms (Dendraster excentricus), polychaetes (especially Scoloplos pugettensis) and oligochaetes constituted most of the remaining standing stock.

Comparing standing stock, however, suspension-feeding bivalves (including Mysella tumida and Psephidia lordi) were the more predominant of the primary consumers at this trophic level. Because the weight of bivalves included that of their shells and these animals are long-lived, their dominance may have been overestimated when calculated from standing stock data. Despite a relatively high average standing stock of macroalgae, herbivores that consume attached plants were sparse and limited to gastropods and amphipods.

Epibenthic omnivorous crustaceans (the mysids Acanthomysis sculpta, A. nephrophthalma, and Neomysis mercedis) and an omnivorous fish (the buffalo sculpin, Enophrys bison) filled the position intermediate between the primary and secondary consumers in their ability to utilize both living and detrital food sources.

Secondary consumers in the food web representing exposed unconsolidated intertidal/subtidal habitats were more diverse and abundant than in any of the food webs discussed previously. Carnivorous nemerteans and polychaetes (primarily Onuphis sp.) and epibenthic planktivorous fishes (12 common species, including redtail surfperch, Amphistichus rhodoterus; juvenile English sole, Parophrys vetulus; and juvenile Pacific tomcod, Microgadus proximus) prey upon the diverse array of epibenthic animals, the majority of which are detritivores. Carnivorous gastropods (including Natica clausa and Nucella sp.) and demersal benthos-eating fishes (8 species, including juvenile starry flounder, Platichthys stellatus; juvenile sand sole, Psettichthys melanostictus; and Pacific staghorn sculpin, Leptocottus armatus) were somewhat less important.

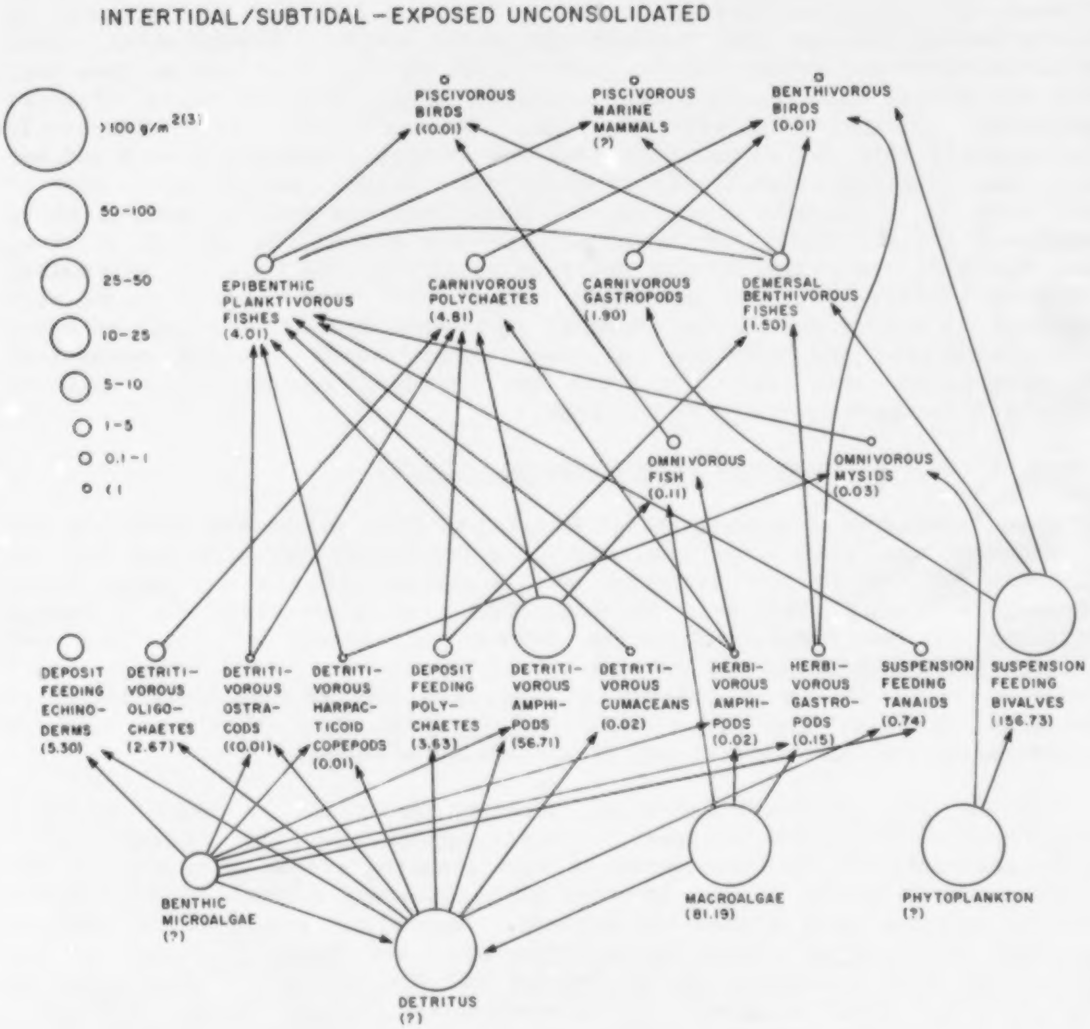

INTERTIDAL/SUBTIDAL - EXPOSED UNCONSOLIDATED
>100 g/m$^{2(3)}$
50-100
25-50
10-25
5-10
1-5
0.1-1
<1
PISCIVOROUS BIRDS (<0.01)
PISCIVOROUS MARINE MAMMALS (?)
BENTHIVOROUS BIRDS (0.01)
EPIBENTHIC PLANKTIVOROUS FISHES (4.01)
CARNIVOROUS POLYCHAETES (4.81)
CARNIVOROUS GASTROPODS (1.90)
DEMERSAL BENTHIVOROUS FISHES (1.50)
OMNIVOROUS FISH (0.11)
OMNIVOROUS MYSIDS (0.03)
DEPOSIT FEEDING ECHINODERMS (5.30)
DETRITIVOROUS OLIGOCHAETES (2.67)
DETRITIVOROUS OSTRACODS (<0.01)
DETRITIVOROUS HARPACTICOID COPEPODS (0.01)
DEPOSIT FEEDING POLYCHAETES (3.63)
DETRITIVOROUS AMPHIPODS (56.71)
DETRITIVOROUS CUMACEANS (0.02)
HERBIVOROUS AMPHIPODS (0.02)
HERBIVOROUS GASTROPODS (0.15)
SUSPENSION FEEDING TANAIDS (0.74)
SUSPENSION FEEDING BIVALVES (156.73)
BENTHIC MICROALGAE (?)
MACROALGAE (81.19)
PHYTOPLANKTON (?)
DETRITUS (?)

Figure 9. Characterization of exposed unconsolidated intertidal/subtidal habitat food web. Average biomass of major taxa represented in parentheses(grams/m^2 or grams/m^3).

Benthos-eating birds, including the Glaucous-winged Gull (71% of the standing stock), Surf Scoter (9%), and the California Gull (7%) dominated the standing stock of tertiary consumers, which also included fish-eating birds (i.e., Great Blue Heron) and marine mammals (the harbor seal).

The standing stock of primary producers was relatively low in these habitats. However, the food web was also highly dependent upon detritus processing. It included many secondary consumers. It also included a high biomass of suspension feeding bivalves. Biomass data for bivalves may be overestimated because they include the dense shells. Nevertheless, these bivalves represent an interesting carbon sink in this food web in that they are not preyed upon by very many species. Thus, standing stock of these molluscs, though comparatively high, is generally not effectively incorporated into the community's food web at higher consumer levels and may have been disproportionally allocated to respiration. Accordingly, most of the turnover of trophic energy within these habitats must be assumed to be regulated and limited by the import of detritus and by the rate of physical and microbial processing of the detritus particles. We have no information on these various processes and their rates. They would appear to be very seasonal in nature due to the seasonal growth and die-off of algae and other plant material, the magnitude of wave action which controls mechanical disintegration, and the temperature and nutrient regimes which regulate microbial decomposition of the detritus.

IV. A. 3. b. (4) Protected unconsolidated habitat.

The influence of topographic protection from winds and currents was evident in the food webs characterizing protected habitats and can be directly related to the structure and stability of the sediments which accumulate there. The most notable effect of protection was a marked increase in the overall diversity (number of nodes) of the food web (Figure 10). High diversity was due to the biomass of benthic infauna, which are restricted in their ability to populate the exposed unconsolidated sediment habitats, and the greater *in-situ* production of plants and the accumulation and retention of detritus produced elsewhere.

While the apparent input of detritus particles in other habitats originates from outside sources, it would appear that the protected-soft/intertidal-subtidal habitats generate high standing stocks of macroalgae and plant material which, if not consumed by herbivores, eventually contributes to the detritus pool within the habitat. Macroalgae common to the habitat included *Enteromorpha* spp., *Rhizoclonium* sp., and *Fucus distichus* in the intertidal zone and *Laminaria saccharina* and *Gracilariopsis sjoestedtii* in the subtidal zone; eelgrass was predominantly *Zostera marina*; saltmarsh plants included a diverse assortment of vascular plants, represented by *Scirpus* (sedges).

Detritus was consumed or processed primarily by deposit-feeding polychaetes (primarily *Lumbrineris* sp., *Owenia fusiformis* and *Tharyx multifilis*) and bivalves (primarily *Macoma nasuta*), which together formed 94% of the estimated total standing stock of detritivores. By contrast, true suspension-feeders were dominated by a diverse group of bivalves, including

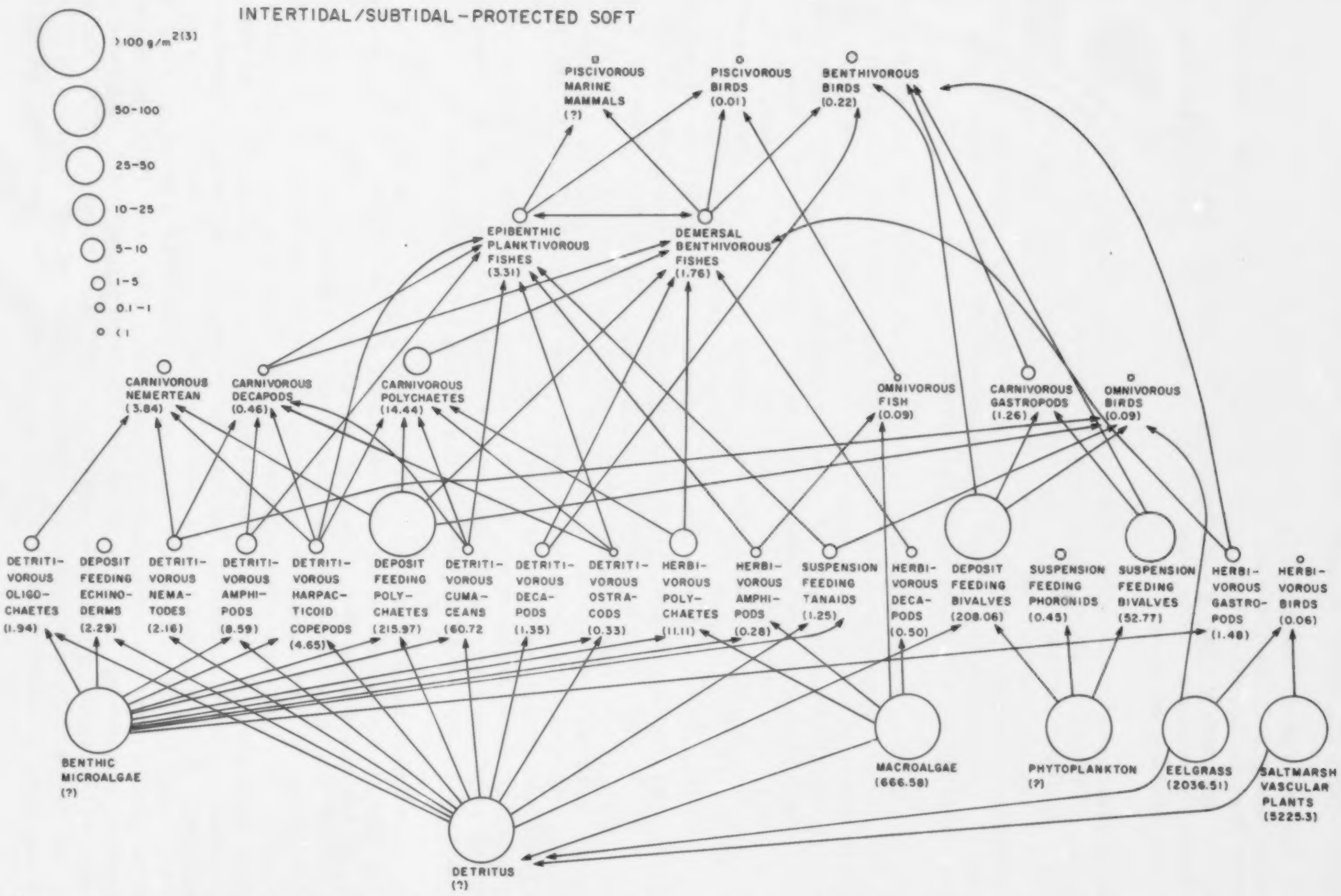

INTERTIDAL/SUBTIDAL-PROTECTED SOFT
>100 g/m2(3)
50-100
25-50
10-25
5-10
1-5
0.1-1
<1
PISCIVOROUS MARINE MAMMALS (?)
PISCIVOROUS BIRDS (0.01)
BENTHIVOROUS BIRDS (0.22)
EPIBENTHIC PLANKTIVOROUS FISHES (3.31)
DEMERSAL BENTHIVOROUS FISHES (1.76)
CARNIVOROUS NEMERTEAN (3.84)
CARNIVOROUS DECAPODS (0.46)
CARNIVOROUS POLYCHAETES (14.44)
OMNIVOROUS FISH (0.09)
CARNIVOROUS GASTROPODS (1.26)
OMNIVOROUS BIRDS (0.09)
DETRITIVOROUS OLIGOCHAETES (1.94)
DEPOSIT FEEDING ECHINODERMS (2.29)
DETRITIVOROUS NEMATODES (2.16)
DETRITIVOROUS AMPHIPODS (8.59)
DETRITIVOROUS HARPACTICOID COPEPODS (4.65)
DEPOSIT FEEDING POLYCHAETES (215.97)
DETRITIVOROUS CUMACEANS (60.72
DETRITIVOROUS DECAPODS (1.35)
DETRITIVOROUS OSTRACODS (0.33)
HERBIVOROUS POLYCHAETES (11.11)
HERBIVOROUS AMPHIPODS (0.28)
SUSPENSION FEEDING TANAIDS (1.25)
HERBIVOROUS DECAPODS (0.50)
DEPOSIT FEEDING BIVALVES (208.06)
SUSPENSION FEEDING PHORONIDS (0.45)
SUSPENSION FEEDING BIVALVES (52.77)
HERBIVOROUS GASTROPODS (1.48)
HERBIVOROUS BIRDS (0.06)
BENTHIC MICROALGAE (?)
MACROALGAE (666.58)
PHYTOPLANKTON (?)
EELGRASS (2036.51)
SALTMARSH VASCULAR PLANTS (5225.3)
DETRITUS (?)

Figure 10. Characterization of protected unconsolidated intertidal/subtidal habitat food web. Average biomass of major taxa represented in parentheses(grams/m^2 or grams/m^3).

Protothaca staminea, *Transennella tantilla*, *Tresus* spp., *Clinocardium nuttallii*, *Tapes japonica*, *Mytilus edulis*, and *Psephidia lordi*.

Of the consumers forming the second trophic level in the food web, 88% were carnivorous polychaetes such as *Dorvillea* spp., *Eteone* sp., and *Exogone* sp. which prey principally upon other polychaetes and meiofaunal crustaceans. Gastropods (primarily *Nassarius mendicus* and *Aglaja diomedea*) were also conspicuous predators upon the high biomass of deposit-feeding and suspension-feeding bivalves.

Epibenthic plankton-eating fishes (primarily shiner perch, *Cymatogaster aggregata*, tidepool sculpin, *Oligocottus maculosus*, juvenile English sole, *Parophrys vetulus*, and rock sole, *Lepidopsetta bilineata*) composed a standing stock of higher carnivores more than twice that of the demersal benthos-eating fishes (primarily Pacific staghorn sculpin and starry flounder). Benthos-eating birds (Glaucous-winged Gull) preyed upon the abundant bivalves in the first consumer level.

The prominence of eelgrass had the functional effect of magnifying both the diversity and standing stock of the food web. Although the diversity of epibenthic zooplankton did not appear to increase within the eelgrass beds, the density and standing crop of these organisms, especially harpacticoid copepods, were orders of magnitude higher than in the areas of these habitats which did not have any eelgrass (Simenstad et al., 1980). And, while the nearshore fish sampling conducted in this region was not designed to separate such microhabitat-associated fish assemblages, there were indications that certain species of nearshore fishes, including bay pipefish (*Syngnathus griseolineatus*), shiner perch (*Cymatogaster aggregata*), silverspotted sculpin (*Blepsias cirrhosus*), penpoint gunnel (*Apodichthys flavidus*), crescent gunnel (*Pholis laeta*), and padded sculpin (*Artedius fenestralis*), were uniquely associated with the eelgrass. Thus, 46% of the epibenthic-feeding fish species in the secondary consumer level of the food web could be attributed directly to the presence of the eelgrass. At this point, however, we cannot verify whether this association was a function of trophic linkages to the epibenthic prey organisms associated with the eelgrass beds or of the structural aspects of the eelgrass beds as hiding places from predators.

Eelgrass also acts to enhance the accumulation of detritus particles by creating low energy zones where suspended matter can settle. Although there is little information on the effect of eelgrass upon the rates of detritus accumulation and decomposition, we can validly assume that the majority of the processing of the detritus particles in these habitats is biochemical rather than physical and that entrapment and retention is conducive to the microbial breakdown of the detritus particles into a form utilized as food by detritivores. The association between detritivorous epibenthic crustaceans and eelgrass also suggests that these animals are probably playing an important role in processing the detritus entrained by the eelgrass plants and whose populations are consequently enhanced. The fact that the majority of detritus processing is a function of biochemical activity suggests that the rate of detritus production available for detritivores would be much slower in these habitats than in physically-controlled habitats but also spread out over a longer time period, e.g., prone to less seasonal variation.

The third role of eelgrass is obvious, for it seasonally supports high densities of herbivorous birds, specifically the Black Brant and American Wigeon, which forage directly upon the intertidal plants during winter and spring in these habitats.

IV. A. 3. b. (5) Summary.

Although the dramatic differences in productivity at different levels of the food web practically negated our ability to compare the characteristic food webs from differing habitats, the comparison of the food web diversity, in terms of the number of feeding groups and standing stock within feeding groups deserves some attention. Table 3 illustrates the proportions of biomass among the trophic groups in the five habitat types represented in the study area. In terms of standing stock of organisms, the rock-cobble intertidal/subtidal habitats had the highest biomass at all levels except the deposit-feeder/detritivores. Suspension-feeders in the exposed unconsolidated/intertidal-subtidal habitats had a higher standing stock than those in the protected soft/intertidal-subtidal habitats, reflecting the influence of dense-shelled bivalves, particularly in subtidal Guemes Island-south area.

From this synthesis it is apparent that diverse communities of organisms have evolved to utilize the divergent sources of plant-produced carbon and detritus available in the region's marine habitats. The rate of flow and distribution of this trophic energy through the food web also varies between communities and appears to be a function of 1) amount and rate of utilizable carbon (detritus, macroalgae, phytoplankton) entering the habitat or generated within it; 2) the stability and spatial heterogeneity of the habitat, and 3) the effect of upper trophic level predators in structuring the lower trophic levels of the communities.

IV. A. 3. c. Species richness, abundance and biomass.

Summaries of the quantitative data collected for each category of organisms are presented in this section. Average values have been calculated for each of the eight habitat types (each habitat usually represented by several specific sampling sites) on a seasonal basis. These data were used to identify major differences between habitats on a seasonal basis. Plants were not included due to the difficulties involved in quantifying them.

IV. A. 3. c. (1) Species richness.

Our present understanding of the distribution of marine mammals precludes any attempts to relate their occurrence to any particular subtidal/intertidal habitat type. However, a few general statements based upon presumed or known behaviors of some species can be made. Harbor seals were most often observed hauled out on protected rock and exposed unconsolidated habitats. Sea lions generally hauled out on protected rock. These occurrences only reflected resting behavior and, in the case of harbor seals, pupping and nursing activities as well. Foraging activities, a critical portion of the time budget of these species, were generally conducted in the nearshore habitats (harbor seals) and offshore habitats (sea lions).

Table 3. Number of feeding groups (in parentheses) and mean annual standing crop (g/m^2 or g/m^3)* in marine habitats of northern Puget Sound and the Strait of Juan de Fuca.

Habitat Types	Primary Producers	Deposit-feeders and detritivores	Micro- and Macroalgae Herbivores	Suspension-feeders	Carnivores	Omnivores
Protected Unconsolidated Intertidal/ Subtidal	(4) 7635.49	(10) 451.36	(3) 13.43	(5) 72.12	(8) 25.42	(2) 1.76
Exposed Unconsolidated Intertidal/ Subtidal	(3) 81.19	(8) 68.35	(2) 0.18	(2) 160.48	(7) 15.53	(2) 0.14
Rock-Cobble Intertidal/ Subtidal	(4) 7842.87	(10) 160.45	(5) 741.40	(5) 647.57	(10) 118.35	(1) 42.81
Nearshore Neritic	(1) 0.40	(0) < 0.01	(0) 0.00	(1) ~ 0.20	(6) 0.27	(1) < 0.01?
Offshore Neritic	(1) < 0.10	(0) < 0.01	(0) 0.00	(1) ~ 0.50	(6) 0.09	(0) < 0.01?

*Standing crop is expressed as g/m^2 in intertidal/subtidal habitats; g/m^3 in offshore and nearshore habitats.

Depending upon the occurrence of sea lions (two species), harbor seals, or river otters, species richness for marine mammals rarely exceeded two at any site.

The mean total species richness values for the other biotic groups are shown in Figures 11-14 for each season. The values reflect the averages of many observations made throughout the study area.

The largest number of bird species, either annually or seasonally, occurred at the protected mud habitat. These data illustrate the importance of areas like Padilla Bay, a protected muddy site, to marine birds. Other habitats having a relatively large number of species throughout the year were the protected mud-sand and mud-gravel habitats along with the exposed mixed coarse habitat. In the fall and winter the cobble habitat also supported a large number of bird species. Year-round, the lowest numbers generally occurred at exposed and protected rock sites. Clearly the lowest number of bird species at nearly all of the intertidal/subtidal habitats were found in the summer.

On an annual or seasonal basis, the number of species of fish was highest at the protected mud gravel habitat; but otherwise the number of species was fairly similar (note that the rock/cobble collections are incomplete). Generally, the lowest numbers occurred at protected rock and exposed sand sites. Seasonally, the tendency was for the lowest number of species in the winter and spring, and the most in the summer and fall.

No seasonal summations of intertidal/subtidal species richness data are available for invertebrates due to unresolvable problems with the data sets. However, species richness was generally highest at exposed rock sites (e.g., Pillar Point, Tongue Point), followed by cobble and protected rock sites. For example, mean annual species richness for rock and cobble sites along the Strait varied from 38 to 169 at the +3 foot tidal elevation; whereas that for other habitats was typically lower (1.5 to 45.3). Species richness was usually lowest at exposed sand and exposed mixed coarse sites.

IV. A. 3. c. (2) Abundance of organisms.

No habitat-related trends in abundance are apparent for marine mammals. Though Table 2 above shows that many of the major harbor seal haul-out areas are rock, their popularity is probably mainly related to isolation from human disturbance rather than the type of substrate.

Total mean abundance of the other biotic groups per habitat type is shown in Figures 15-18 per season. The reader should note that the abundance of invertebrates is about 10^4 times greater than that of fish or birds as is indicated on the vertical axis label of Figures 15-18. Also, the abundance values for tidepool fishes at rock and cobble habitats have not been included because they were not obtained in a comparable manner to other nearshore fishes.

Bird abundance was quite seasonal but one habitat, the protected mud-sand habitat such as found at Jamestown, had relatively high numbers

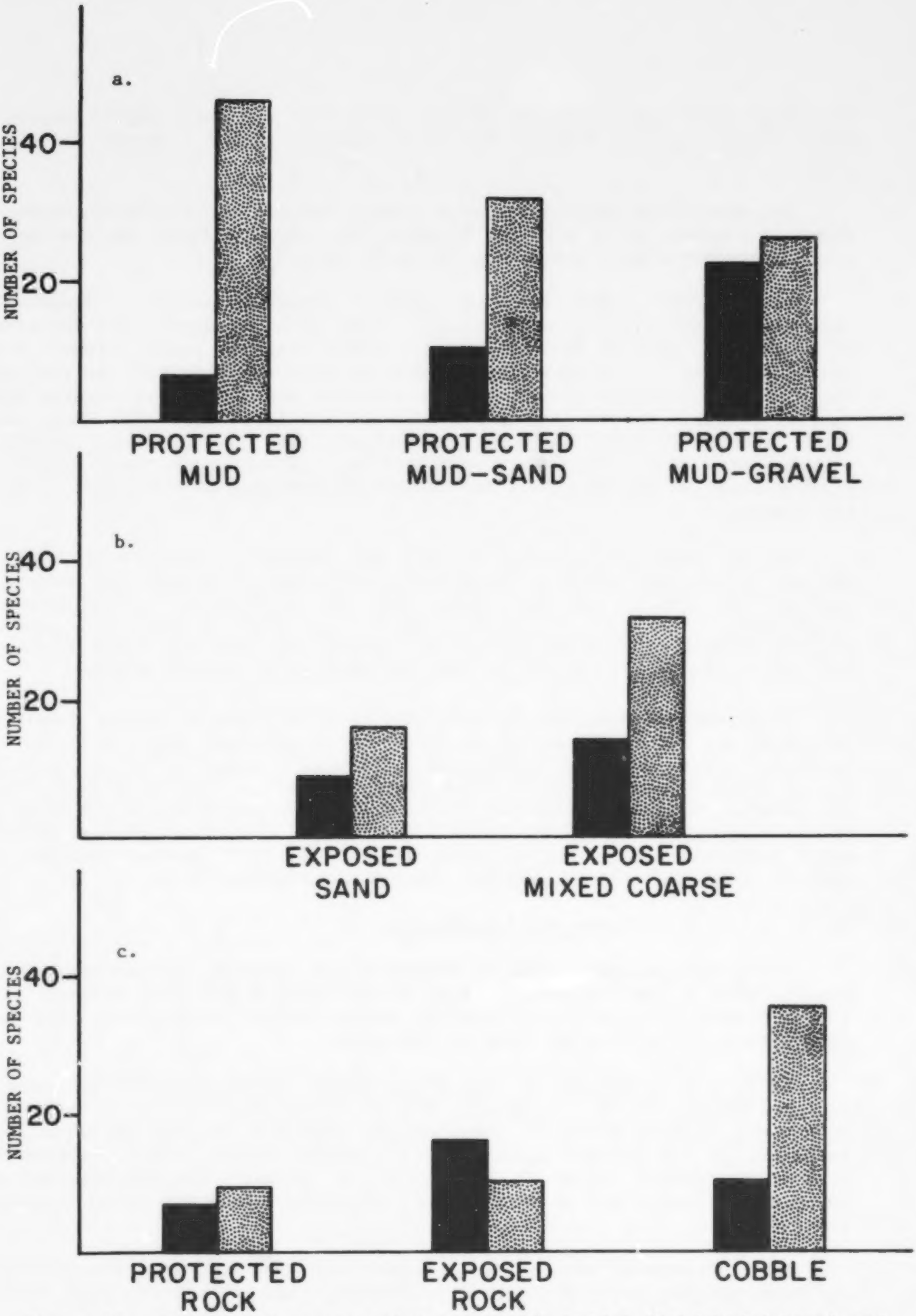


Figure 11. Numbers of species of intertidal/subtidal fish(shaded bars) and birds(hatched bars) in the winter at (a) protected habitats, (b)exposed habitats, and (c) rock and cobble habitats.

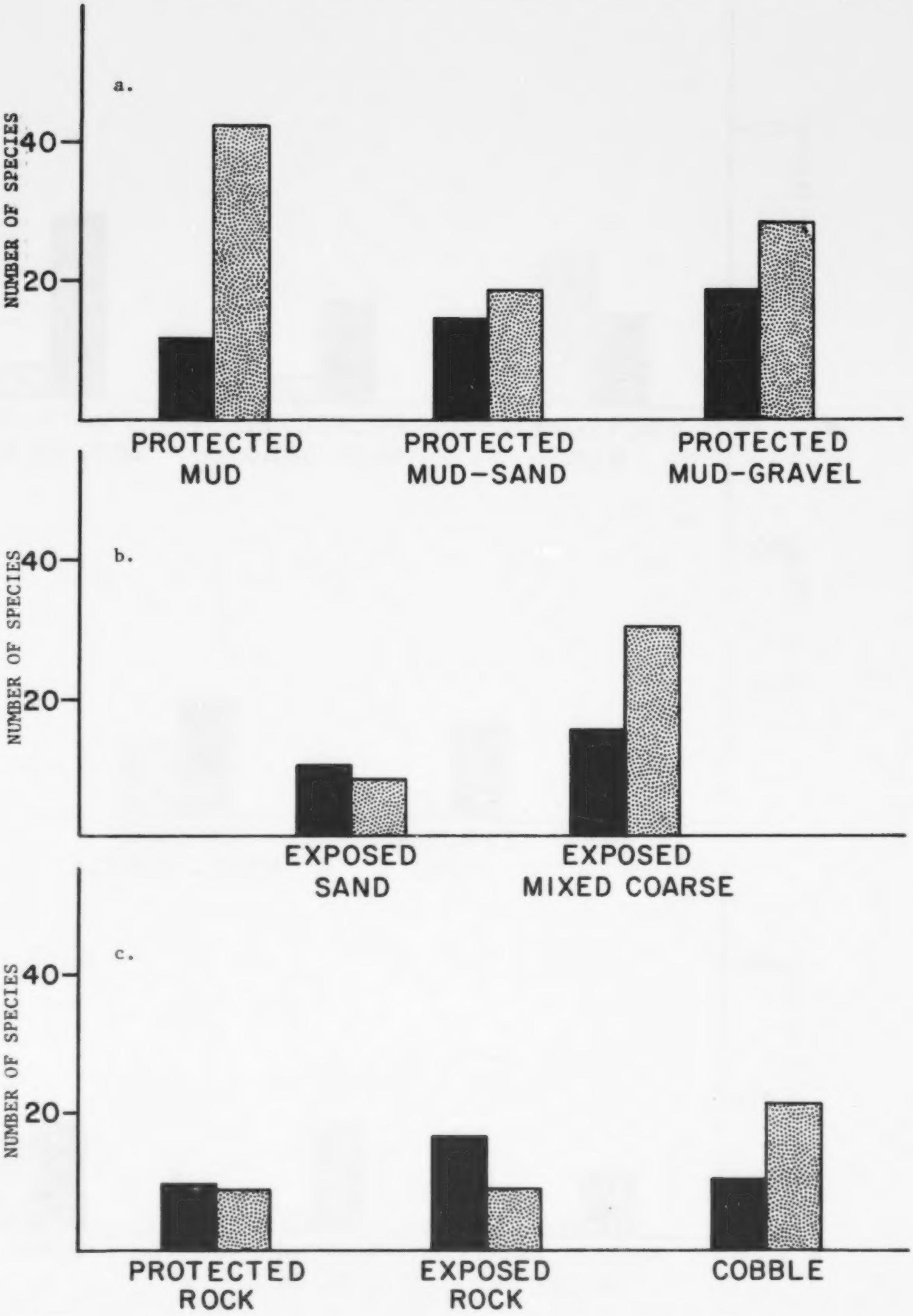


Figure 12. Numbers of species of intertidal/subtidal fish(shaded bars) and birds(hatched bars) in the spring at (a) protected habitats, (b) exposed habitats, and (c) rock and cobble habitats.

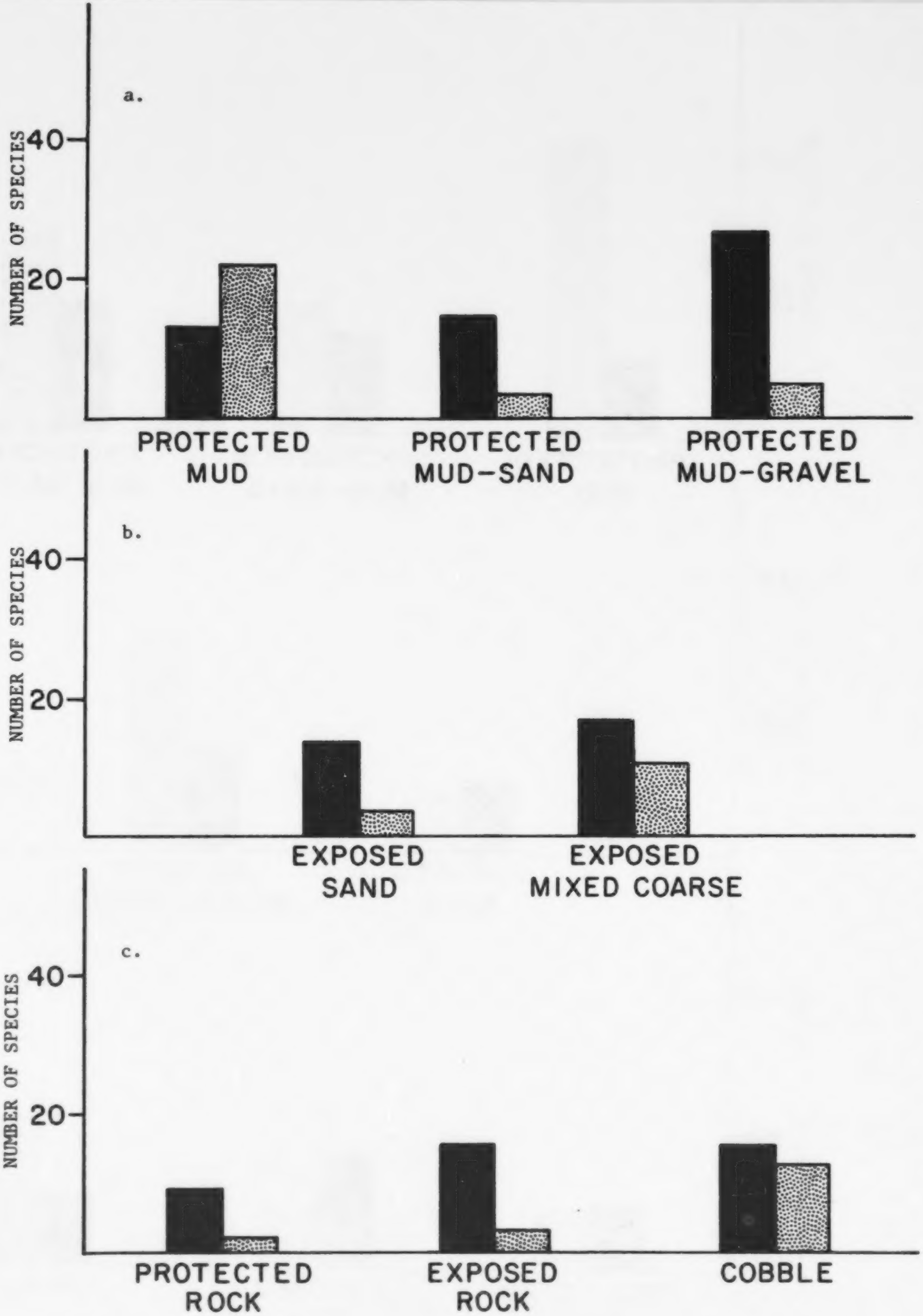


Figure 13. Numbers of species of intertidal/subtidal fish(shaded bars) and fish(hatched bars) in the summer at (a) protected habitats, (b) exposed habitats, and (c) rock and cobble habitats.

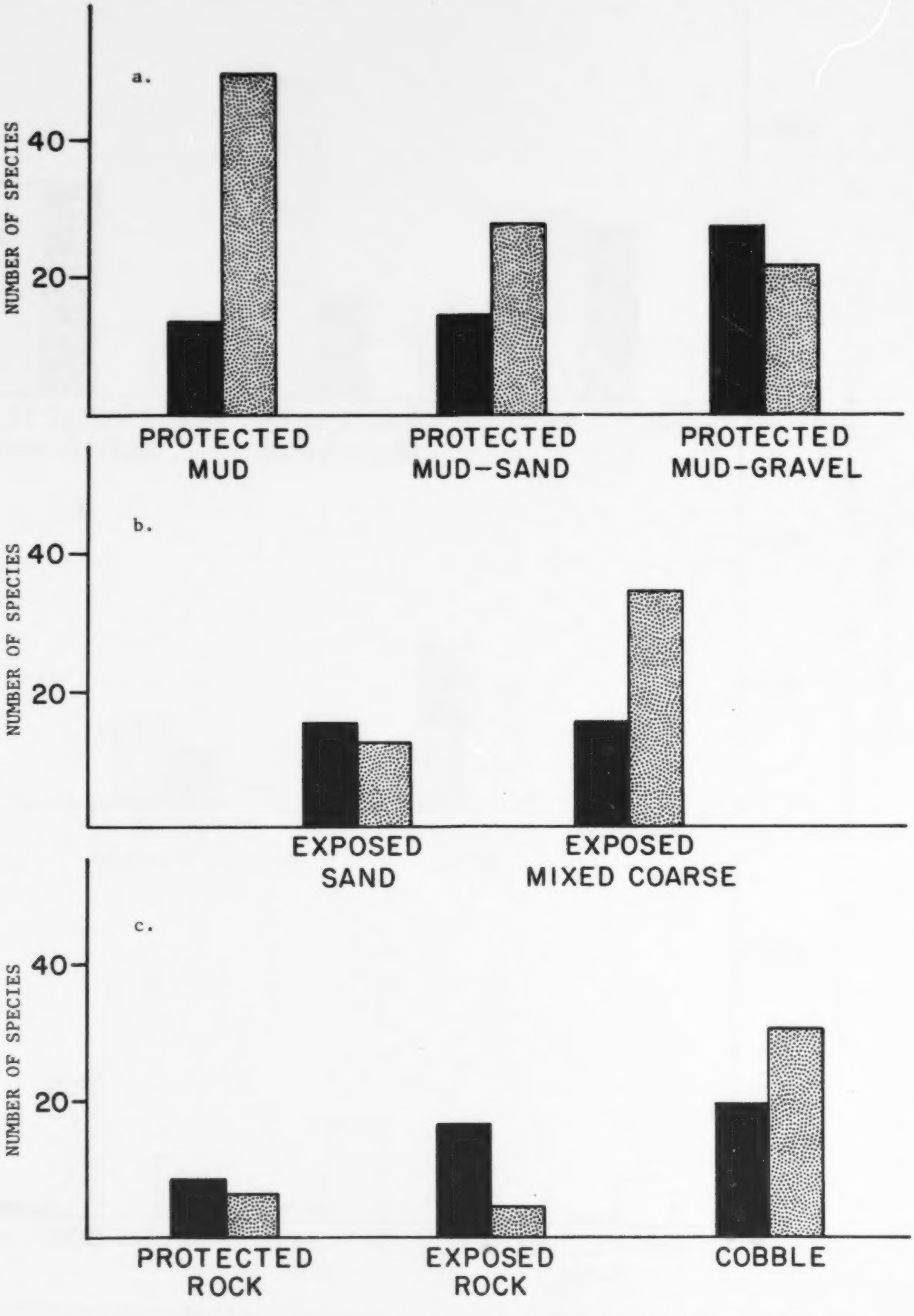


Figure 14. Numbers of species of intertidal/subtidal fish(shaded bars) and birds(hatched bars) in the fall at (a) protected habitats, (b) exposed habitats, and (c) rock and cobble habitats.

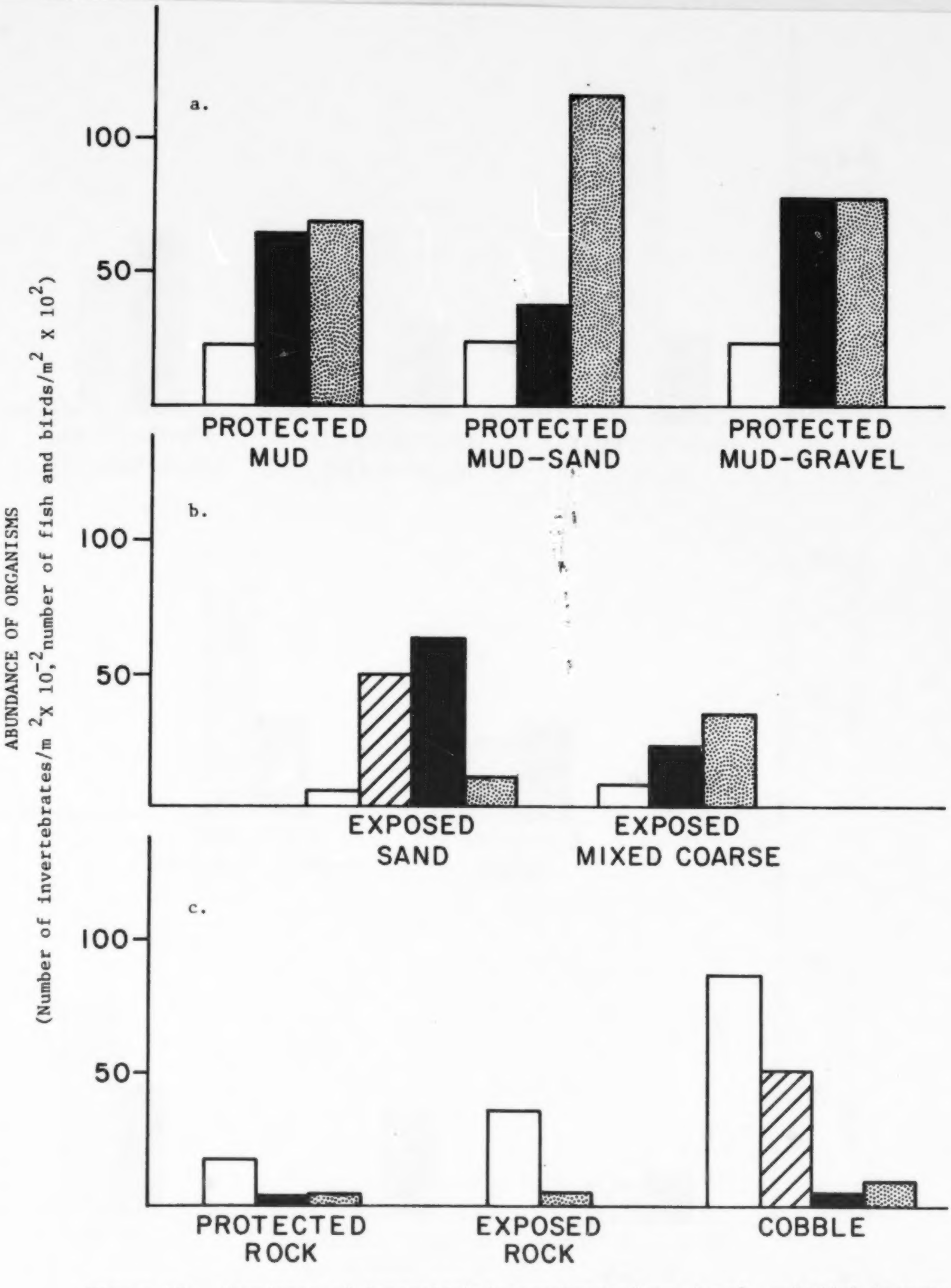


Figure 15. Abundance of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the winter at (a) protected, (b) exposed and (c) rock and cobble habitats.

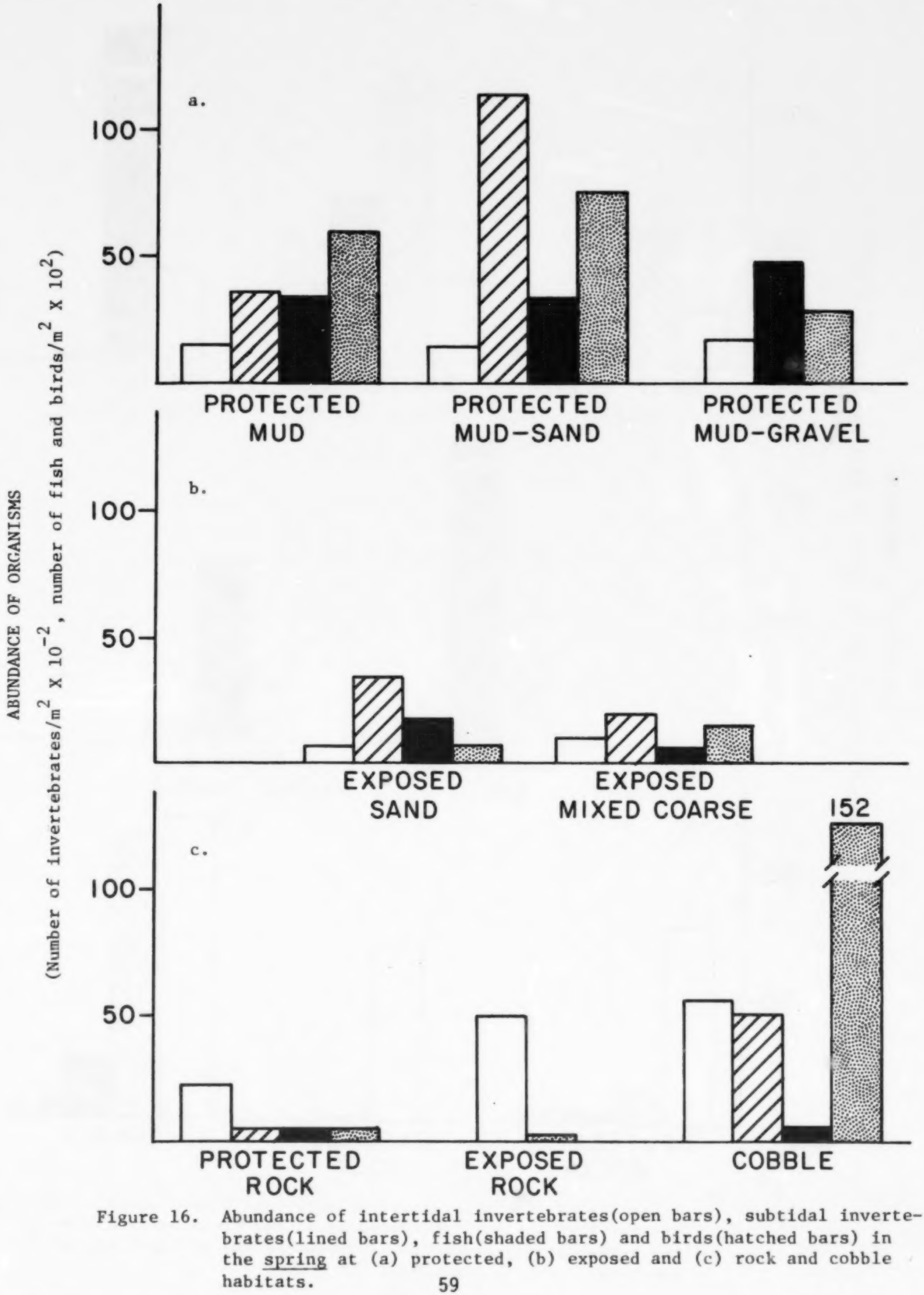


Figure 16. Abundance of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the spring at (a) protected, (b) exposed and (c) rock and cobble habitats.

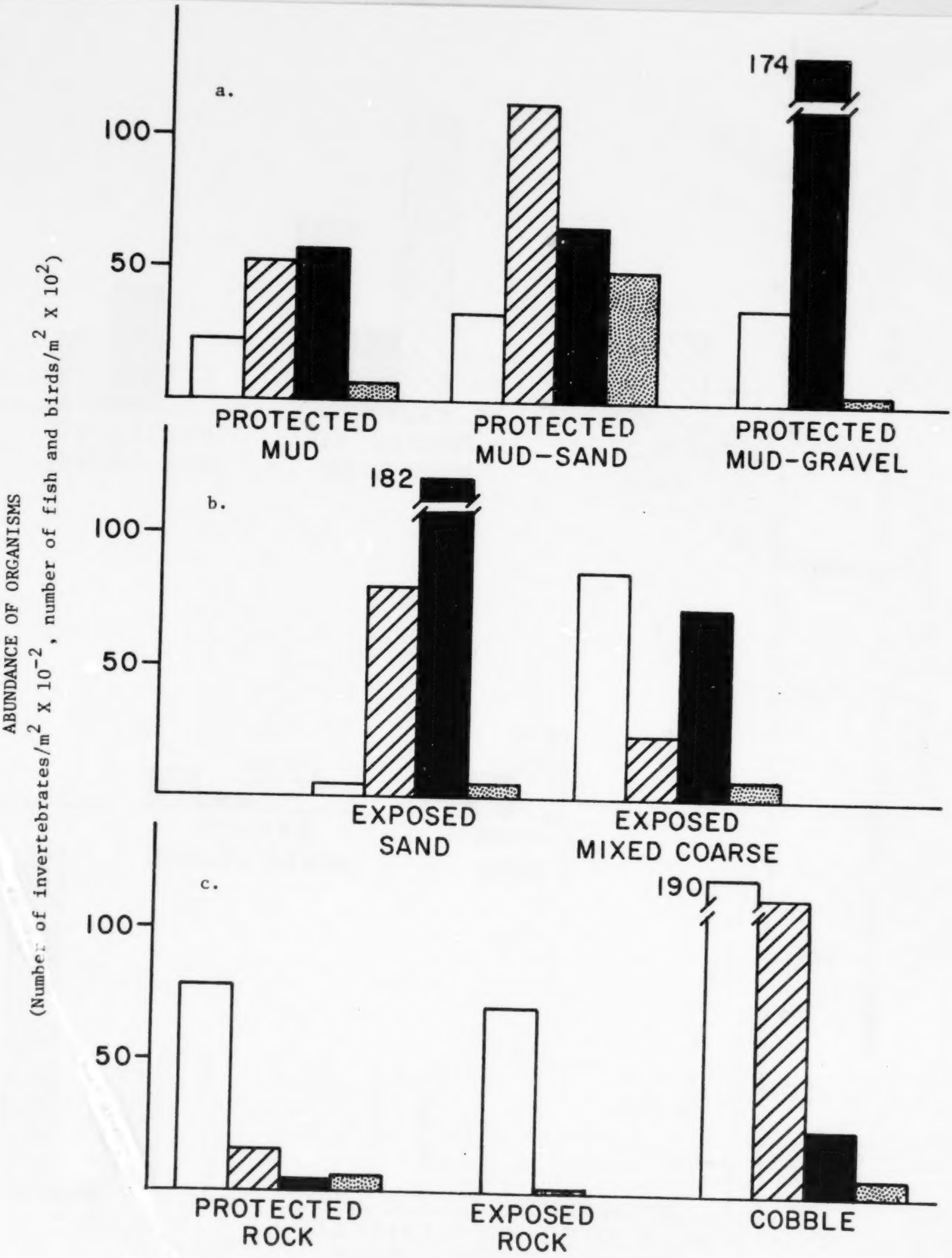


Figure 17. Abundance of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the summer at (a) protected, (b) exposed and (c) rock and cobble habitats.

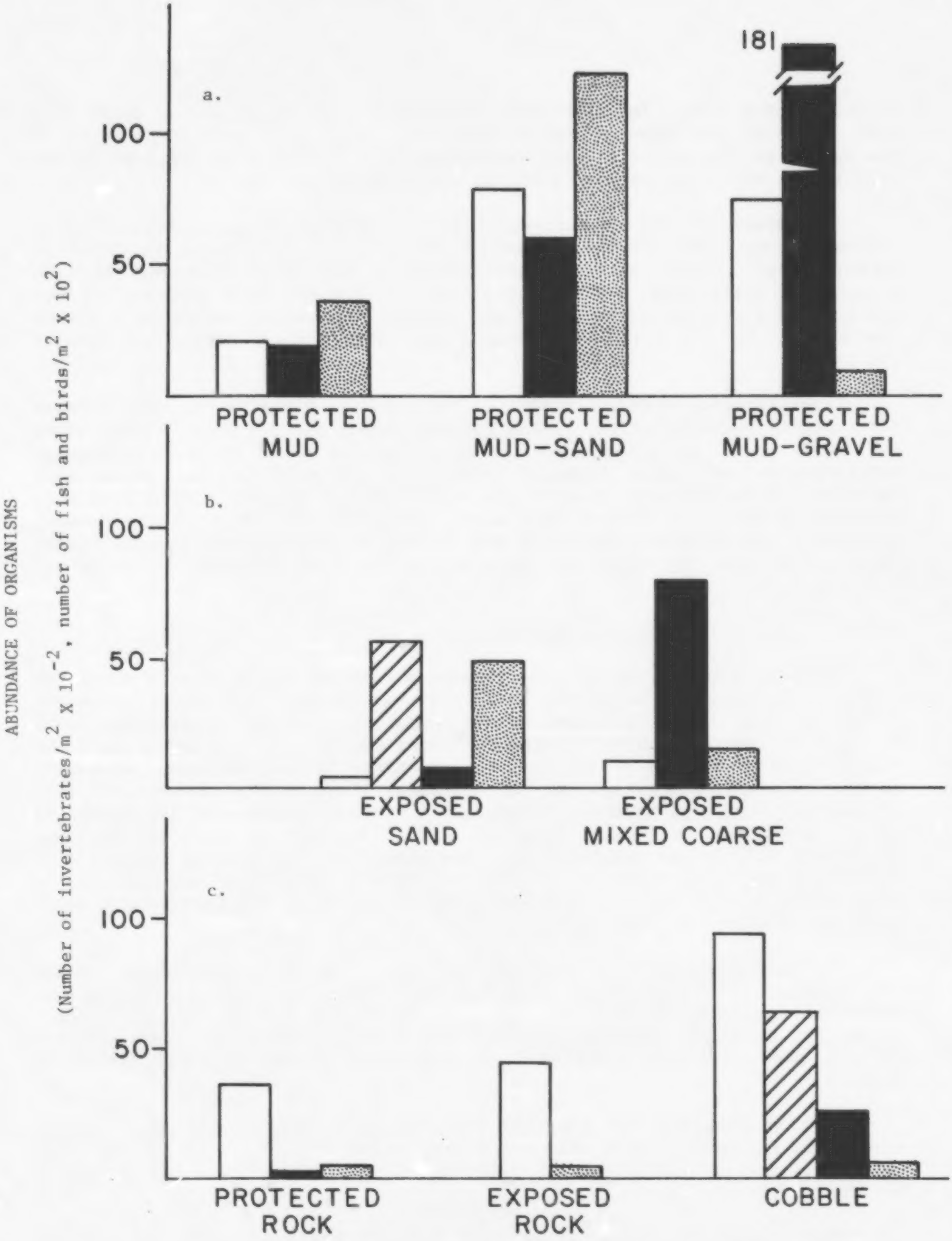


Figure 18. Abundance of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the fall at (a) protected, (b) exposed and (c) rock and cobble habitats.

throughout the year. In the winter, relatively high abundances of birds were also found at the other protected habitats. Very high numbers occurred in the spring at the cobble habitat associated with herring spawning, and in the fall fairly high numbers were found at the exposed sand habitat.

Fish abundance was characterized by consistently high numbers of fish throughout the year at the protected mud-gravel habitat such as found at Beckett Point. Other habitats where numbers of fish were relatively high on a seasonal basis were the protected mud and exposed sand habitats in the winter, the protected mud/mud-sand and exposed sand/mixed coarse habitats in the summer, and the protected mud-sand and exposed mixed coarse habitats in the fall.

Invertebrates, both in intertidal and subtidal zones, stand out as being particularly abundant at the cobble habitat throughout the year, illustrating the dense biota at sites like Cherry Point and Morse Creek. Intertidal invertebrates were also abundant throughout the year at the other rock habitats (protected and exposed) and the protected unconsolidated habitats. With the exception of some exposed mixed coarse habitat sites in the summer, intertidal invertebrate abundance was lowest at the exposed unconsolidated sites. Subtidal invertebrates appeared to be most abundant at protected mud-sand sites.

IV. A. 3. c. (3) Biomass of organisms.

Our understanding of the role of marine mammals in the aquatic ecosystem is not clear enough to allow for an accurate assessment of biomass by season by habitat type. The fact that harbor seals may haul out on protected rock habitats in greatest numbers in the fall does not necessarily imply that the sum of their biomass is of any special importance to that habitat. As marine mammals relate to the ecosystem, their biomass plays a significant role only in the nearshore and offshore habitats. A minimum estimate of the number of harbor seals in the study area is 1,900 (Everitt et al., 1980), and individual animals may reach 110 kg. Sea lions occur in smaller numbers with California sea lions numbering to 300 individuals (primarily males which can weigh up to 275 kg) and northern sea lions numbering to 260 individuals (with potential weights to 1,000 kg).

The reader should note that the biomass values of invertebrates are on the order of 10^2 times larger than for fish, and 10 times larger than for birds--as indicated in the vertical axis of Figures 19-22. Also, biomass values for tidepool fishes at rock and cobble habitats have not been included because they were not obtained in a comparable manner to other nearshore fishes.

Bird biomass was consistently high at the protected mud-sand habitat throughout the year. On a seasonal basis, relatively high biomass was seen at the protected mud/mud-gravel habitats in the winter and at the cobble habitat in the spring.

Fish biomass, besides being very high at the protected rock habitat throughout the year, was also relatively high at the protected mud-gravel

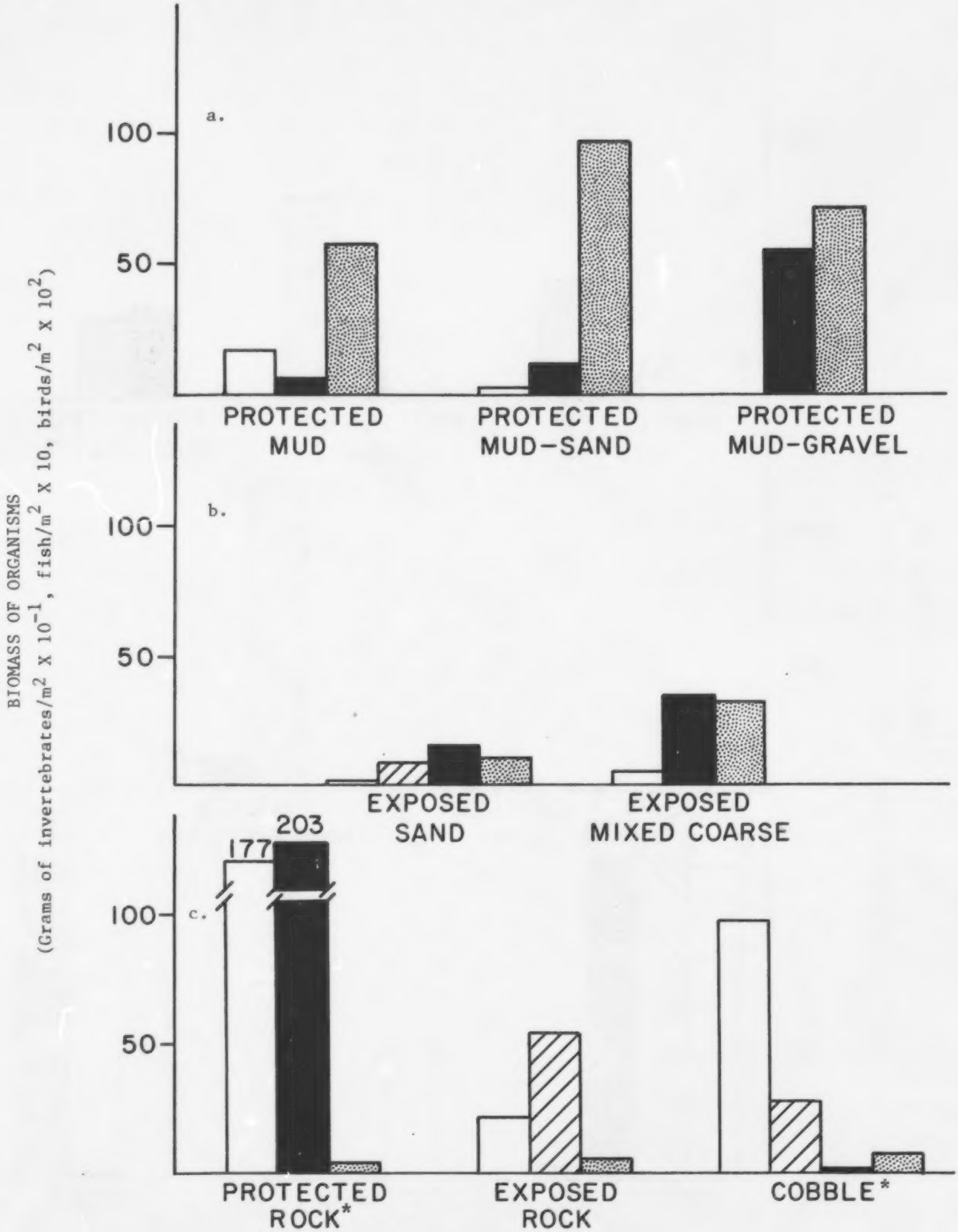


Figure 19. Biomass of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the winter at (a) protected, (b) exposed and (c) rock and cobble habitats. *Does not include tidepool fishes.

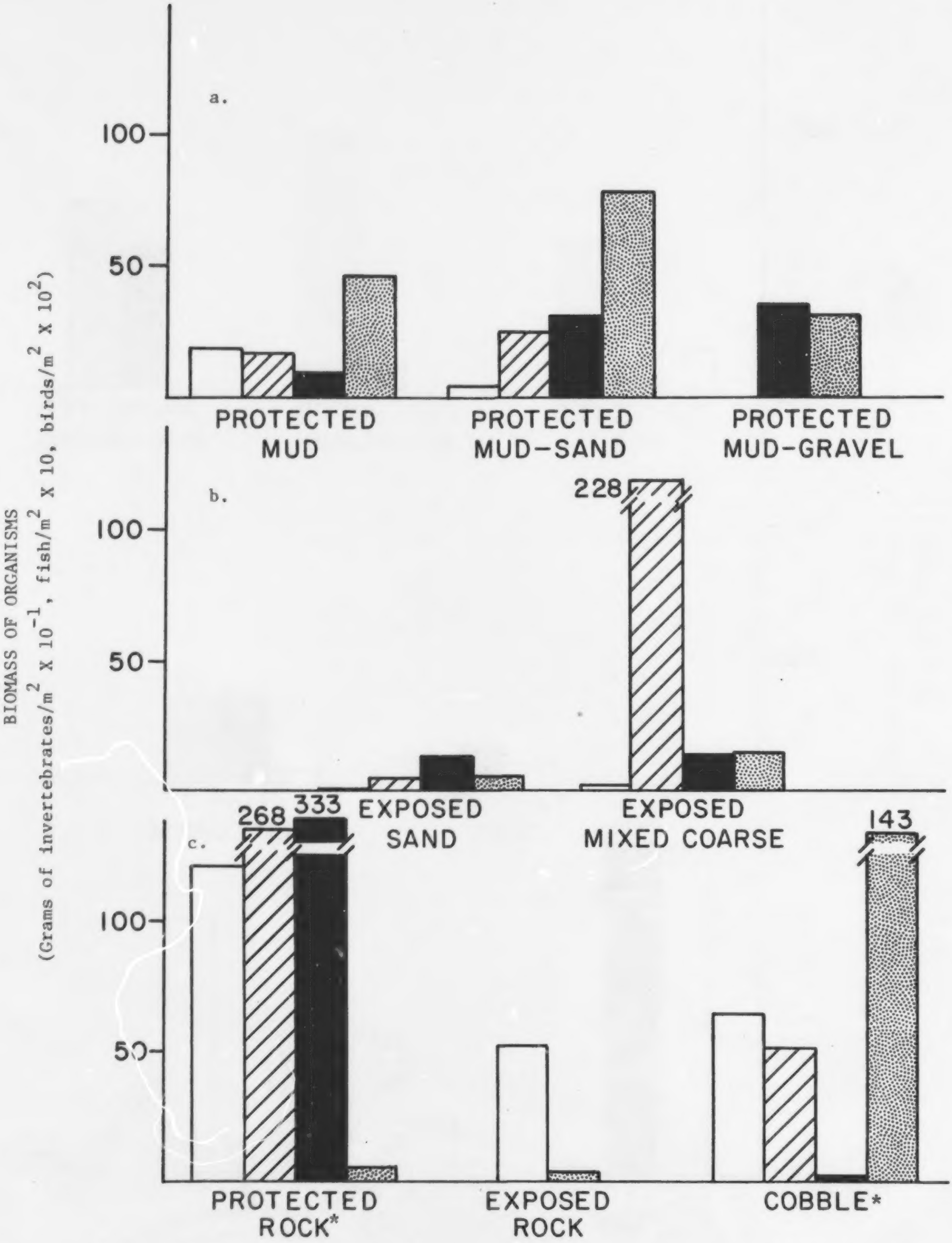


Figure 20. Biomass of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the spring at (a) protected, (b) exposed and (c) rock and cobble habitats. *Does not include tidepool fishes.

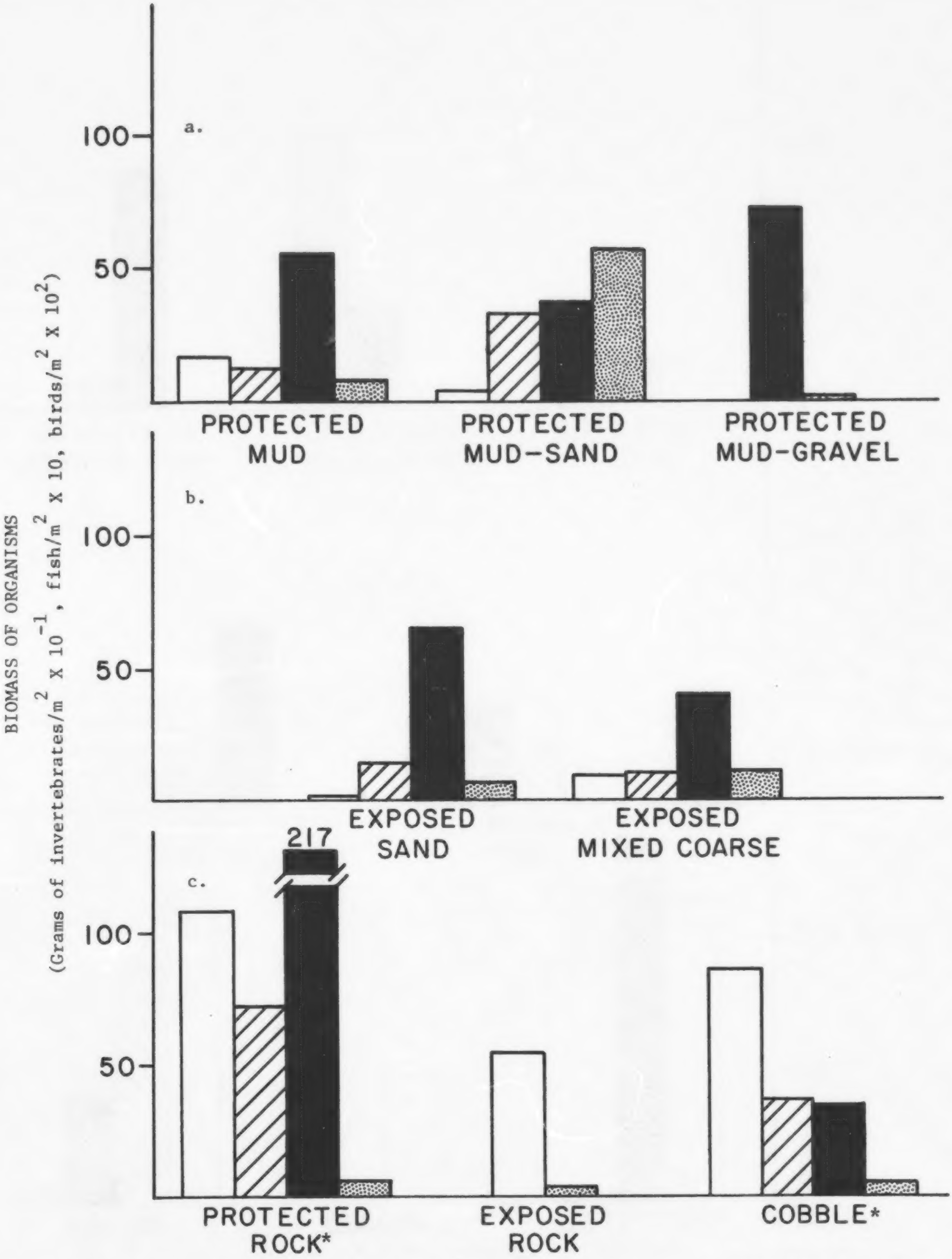


Figure 21. Biomass of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the summer at (a) protected, (b)exposed and (c) rock and cobble habitats. *Does not include tidepool fishes.

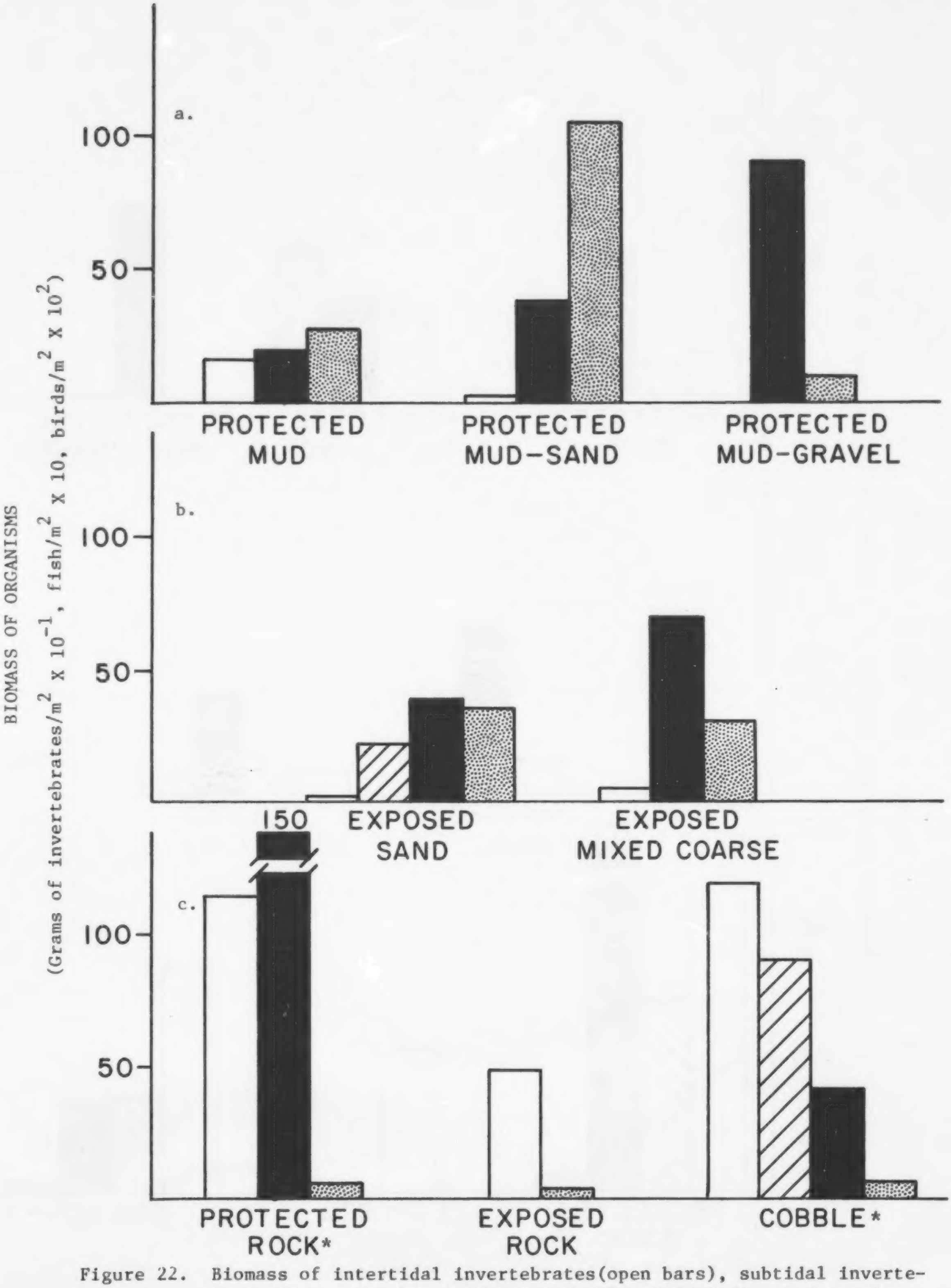


Figure 22. Biomass of intertidal invertebrates(open bars), subtidal invertebrates(lined bars), fish(shaded bars) and birds(hatched bars) in the fall at (a) protected, (b) exposed mud and (c) rock and cobble habitats. *Does not include tidepool fishes.

habitat throughout the year. Seasonal highs for fish biomass were seen at the protected mud and exposed sand habitats in the summer and at the exposed mixed coarse habitat in the fall.

The most obvious feature of the graphed biomass data is that biomass for most groups was highest at either protected unconsolidated habitats or rock habitats. Both invertebrates and fishes had very high values at the protected rock habitat during all seasons. The high biomass values for invertebrates were due to the occurrence of many large and/or dense-shelled invertebrates. Because of these same biotic groups, invertebrate biomass was also relatively high during all seasons in the cobble habitat. In the spring, the subtidal invertebrate biomass was high in the exposed mixed coarse habitat.

IV. A. 3. d. Migrants.

IV. A. 3. d. (1) Rock/cobble.

Marine mammals: Sea lions are the only migratory marine mammals that utilize rock habitats primarily for resting. Sea lions move into the study area from breeding grounds further north and south and are most abundant in the winter. Total combined counts of over 300 animals have been recorded during winter surveys. Neither the seals nor the sea lions apparently use the cobble habitat in the study area for hauling out.

Birds: Census data did not permit differentiation between exposed and protected rock types. The seabird censuses were not focused closely enough on shoreline intertidal/subtidal habitat types to include only migratory species associated directly with rock substrate. The censuses at Fidalgo Head, for example, included diving ducks foraging off nearby Shannon Point (a different substrate); thus, the data in Appendix Table III-B do not characterize Fidalgo Head itself. Of the very large numbers of migratory birds which may be observed nearby, only a very few use rock substrate habitats for foraging.

Yearly peak numbers of migratory birds were much lower than those in other habitats, but migrants occurred in fall through spring. They included Harlequin Ducks and small numbers of "rock" shorebird species: Black Turnstones, Surfbirds, a few Rock Sandpipers, Ruddy Turnstones, and Wandering Tattlers. Gulls included resident Glaucous-winged Gulls, but also migrant and wintering species like California, Mew, Bonaparte's, and Heermann's Gulls. Migrant gulls were observed foraging in rocky intertidal areas, but often used rocks above tidal influence for resting and waiting for feeding opportunities in tidal fronts offshore. Black Oystercatchers are a resident species, but form flocks in winter (up to 40 birds) which appeared to move about among rock habitats of the study area.

Seabird data for cobble substrates were obtained at the Cherry Point area. Populations there were characterized by great seasonal variations. The lowest numbers were found during the summer months. Large numbers of migratory diving ducks often appear in the fall and spend the winter along this shoreline. The density of birds and the seasonal range in abundance were usually lower in cobble habitats where Pacific herring do not spawn. The most abundant species (Appendix Table II-B) included Greater Scaup, Common Goldeneye, Bufflehead, Harlequin Duck, White-winged and Surf Scoters. In addition to resident Glaucous-winged Gulls, wintering Mew Gulls and spring and fall migrant Bonaparte's Gulls used the cobble habitat. Along the Strait of Juan de Fuca, Heermann's Gull was a common migrant and summer resident. Shorebirds did not occur in appreciable numbers in cobble habitats, though some species like Black Turnstones may forage there on occasion during migration. The presence of Sanderlings on Appendix Table II-B represents occurrence in an adjacent habitat, not in cobble itself.

Fish: The single most obvious seasonal feature of the cobble habitat type involving migratory fish is the Pacific herring spawn in late winter-spring. Along the eastern Georgia Strait this phenomenon represents the end result of a large migration of this species in nearshore waters, with herring eggs deposited on intertidal/subtidal vegetation, rocks, and pilings. The cobble areas and adjacent exposed unconsolidated habitats are one of the most important marine spawning habitats in the study area. The herring spawning activity, in turn, attracts very large numbers of birds described above. In eastern Georgia Strait, it takes place when marine birds are moving northward in the spring; and for some populations this phenomenon may represent an important staging/feeding concentration during migration.

IV. A. 3. d. (2) Exposed unconsolidated.

Marine mammals: The only species of marine mammal utilizing the exposed unconsolidated habitat to any significant degree is the nonmigratory harbor seal. The migratory sea lions apparently do not use this habitat type for hauling out, though they may forage in the subtidal zones.

Birds: Birds of the two exposed unconsolidated habitats--mixed coarse and sand--had similar species and seasonal characteristics (Appendix Tables III-D and III-E). Patterns of migration involved essentially a passage of several gull species and Common Terns through the area during the fall; an influx of large numbers of diving ducks in the fall for the overwintering; and a subsequent emigration of these ducks in the spring.

Bald Eagles, found in small numbers on most shorelines of the study area, were observed more frequently along the shorelines of the San Juan Islands. They migrated into the area during the winter. As in other shoreline habitats, a large proportion of the fall gull populations were using the shorelines for resting between foraging flights offshore.

Exposed unconsolidated habitats generally support few shorebirds, although these are characteristic habitats for Sanderlings. This species, while common on the outer coast of Washington, occurs in small numbers as a spring and fall migrant and as a winter visitor in the study area.

Fish: Important movements of a number of fish species are known to take place in or adjacent to exposed unconsolidated habitats. These include juveniles of important commercial species, especially pink and chum salmon, and including chinook and coho salmon. Pacific herring accounted for 76% of total numbers of fish and 75% of total biomass in samples taken in our studies. Long-finned smelt and sand lance were also taken, though in smaller numbers. Maxima in species richness and standing stocks in summer and minima in winter apparently reflect large migrations of herring.

IV. A. 3. d. (3) Protected unconsolidated.

Marine mammals: Similar to what was observed at exposed unconsolidated habitats, migratory marine mammals apparently do not use this habitat type to haul out, though they may forage in subtidal zones.

Birds: Seasonal migration patterns for the three types of protected soft habitats were found to be similar and magnitudes of movements were large. Very large numbers of diving ducks (Appendix Tables III-F-H) moved into the protected unconsolidated areas in the fall and remained through spring. Where eelgrass was present, species like Black Brant and American Wigeon also occurred in large flocks. The Black Brant had a somewhat atypical migration pattern, with very large numbers occurring in most habitats only during northward spring migration. Only a small number of protected eelgrass emabyments had wintering brant populations, though the species was widespread from March into May. The significant migrations of the two primary eelgrass-associated species in and out of most bays were not duplicated in Westcott Bay, where neither species was recorded in 1978-1979.

Sizable migrations of dabbling ducks and several species of gulls also took place to and from protected unconsolidated habitats. A number of these species also wintered in the area, from about September through April. Because these habitats supported many species during the year and Appendix Table II-B gives only the 10 most frequently occurring species, there were many other species that occurred in sizable numbers that were omitted from the tables.

Protected habitats were the most important areas for Great Blue Herons, with highest populations in summer and early fall, and with most birds apparently moving out of the area during the winter. These were also the primary habitats for shorebirds, such as Killdeer, Sanderling, and Black Turnstone. These habitats have been reduced by human activities in the study area, but still support considerable migrant populations of species like Semipalmated Plover, Whimbrel, Greater Yellowlegs, Short-billed Dowitcher, and Western Sandpiper. Dunlins arrived in late fall and winter in the study area in large numbers, and flocks of Black-bellied Plovers wintered locally.

Fish: Pacific herring often spawn in protected soft habitats in eastern Georgia Strait, through this migration/spawning is of a much lesser scale than nearby exposed cobble and unconsolidated habitats. There appears to be movement of Pacific herring larvae into protected habitats after hatching. Frequently, there are also movements of salmonids, particularly juvenile chum salmon, in and out of these areas.

IV. A. 3. e. Variability between and within habitat types.

IV. A. 3. e. (1) Introduction.

The division of the nearshore region into physically defined habitat types rests upon the assumption that biological communities are closely related to general substrate profiles and exposure. Within habitat types, similarity in species richness, biomass, and abundance might be expected. Reasonably similar distribution of species with season and, where appropriate, with tidal elevation might also occur.

Thus far, mean abundances of species per unit area have been presented without particular comment on the variation associated with those means. Variation in species abundance has been reported in various ways by the individual investigators. For benthos and dominant bird species, means and standard deviations were available. Webber (1980) reported the percent of species whose coefficients of variation, as $s/\bar{X} \times 100$, were greater than 100%. Miller et al. (1980) calculated the power of the test for detecting hypothetical decreases in fish numbers or biomass. Variability in fish prey spectra was described by calculating an Index of Affinity, which is a pairwise coefficient of similarity for Index of Relative Importance (I.R.I.) values. For marine mammals, probable factors in observed variation in numbers were discussed in the text, but no statistical analyses were performed (Everitt et al., 1980). In general, the variation observed probably arises from several interacting factors; and under the sampling programs used it is usually not possible to tell which factors had major effects.

The first section of this discussion focuses on sources of variation in sample means which can be demonstrated in the data, and the second section describes briefly the overall magnitude of variation in the major habitat types. In some cases it is possible to postulate causes for major variation, but most of the variation could be due to a number of different and not necessarily mutually exclusive causes.

IV. A. 3. e. (2) Sources of variation.

Main sources of variation in sample means for MESA/WDOE survey data can be divided into variation arising from sampling design, and that arising from natural unpredictability of population abundance within habitats.

Aspects of sampling design that affect measures of variation are: 1) habitat definition, 2) control of variable factors within habitats, 3) reasonable levels of replication and appropriate sample area, and 4) quality control. In all surveys, efforts were made to ensure that reasonable confidence could be placed in the results, given the constraints of available time and funding. However, the efficacy of the designs in estimating species richness and abundance was not thoroughly investigated.

Some elements of habitat definition for all the surveys were substrate type and extent of the defined habitat type. For fish and bird surveys, water depth formed another element of habitat type. Substrate type was consistently described, although standard grain size analyses with adequate replication were not always performed. For mobile species, such as birds, mammals, and fishes, considerable movements over boundaries of substrate type were qualitatively described. Individual bird census tracks could not always be broken down by substrate type, nor was it considered appropriate to do so. The benthic survey sites were chosen based partly on substrate specificity, but the definition of substrate type was largely descriptive, rather than quantitative. As a result, habitats defined as equivalent exhibit some degree of difference in patterns of species occurrence and abundance. Exposed mixed coarse sites are a case in point. Mean water depth was at least estimated for fish and bird habitats. Especially strong increases of bird species richness and abundance in shallow water versus deeper water supports the use of water depth in defining habitat for these censuses.

The effect of habitat extent on the abundance, occurrence, and preditability of species holds promise for future study for all the animal groups, but was not specifically investigated in the baseline program. One example of the effect was described by Miller et al. (1980). Fish species are more numerous at the pocket gravel beaches on San Juan Island (Eagle Cove, Deadman Bay) than at gravel beaches with longer extent, such as South Beach and Dungeness. This trend occurred because demersal fish species from nearby rock, kelp, or eelgrass habitats probably regularly forage in the gravel area. Local levels of abundance of birds and also of benthic species could be influenced by habitat extent as well. For instance, Osman (1978) showed that species richness of benthic species colonizing submerged plates increased as the area of the plate increased. A relative increase in immigration was hypothesized to account for this increase. This effect may only be seen where the habitats are substantially heterogeneous, since species immigration in habitats of large extent might be reduced.

Variation in physical factors within habitat types probably influences both mobile and sessile species. Some of these factors are at least related to season, elevation above Mean Low Low Water (MLLW), hydrographic conditions, weather, tide stage, and both chronic and catastrophic disturbance.

For benthos, variables that were consistently present were thought to be the most important. Seasonal and elevation differences were investigated at each habitat, and fairly undisturbed sampling sites were chosen. Subtidal sampling took place at the same tide stage in each season, to minimize this possible source of variation. Local weather and hydrographic conditions were not recorded continuously, so observed year-to-year variation in benthic species abundance is difficult to relate to these variables. A massive die off of limpets has been reported during the simultaneous occurrence of low tides and hot weather in California (Wolcott, 1973). In the study area, mortality caused by depressed salinity during heavy runoff could also occur. Differences in the magnitude of salinity and temperature fluctuations could make the difference between normal mortality or catastrophic mortality, especially if juvenile forms suffered high mortality in one year but not in another. In the MESA/WDOE baseline surveys, distinctions between year classes were not routinely attempted. Even when massive recruitments were seen, it was impossible to tell whether physical conditions were a major cause or whether combinations of purely biotic interactions were more important or had a magnifying effect.

Variability factors were observed and often at least indexed in bird and fish surveys, but the level of replication made control of any but seasonal differences difficult. Such factors as tide stage and weather conditions are thought to affect species abundances for both groups. One simple example is the use of shallow bays at low tide versus at high tide. Sampling was controlled to a great extent, but apparently minor differences in tide stage may result in large changes in bird numbers. For instance, diving birds obviously do not wait for the tide to go all the way out before leaving a shallow area. Some bird species, such as dabbling ducks, may keep to a relatively constant water depth during an ebbing tide; while others, such as some gull species or diving birds, may move offshore and completely out of the area before the tide has ebbed very far at all. The effects of disturbances, such as bird-watching or hunting, also contribute to variation in census results. While attempts may be made to avoid censusing during disturbances, it is often not possible to know in advance that they will be occurring.

Fish sampling was also designed to avoid variation arising purely from physical factors. Use of sinking and floating beach seines and of tow-nets was designed to capture species inhabiting all parts of the water column. Beach seine collections were taken at low tide. Tow-net samples were taken at night, both with and against the prevailing tidal current. Day versus night beach seine variation was hopefully reduced by the concentrating effect of sampling at low tide. However, gear avoidance in daytime sampling may still contribute significantly to catch variation. Likewise, variation in the strength of tidal currents probably accounts for some of the variation in tow-net samples. Tow-net catch efficiency may also vary at different effective sampling velocities. Problems with gear selectivity and quantitative inadequacies of nets are well-recognized among fishery biologists.

Mammal surveys were focused on pinniped haul-out sites. Substrate type had less significance than for other species; for example, harbor seals show very little habitat specificity. Tide stage and time of day were controlled and noted in the sampling design. Seasonal differences were analyzed also. The result is that haul-out numbers at specific locations are not particularly variable especially during summer. There were apparent differences in the degree of variation between haul-out sites. For instance, the coefficient of variation (CV) in the mean number at Protection Island in 1977-1978 for the entire year was 0.3, and was comparable in each season. At Smith-Minor Island, the yearly CV was 0.6, but it was 0.1 in summer months. Whether this is a significant difference or not is unknown. Mammal survey data were particularly sensitive to disturbance caused by people, dogs, planes, and boats.

It is imporant to realize that the numbers of each species reported for the study area represent simple counts of the most easily observed individuals and were not extrapolated to an estimate of actual abundance.

Thus, the maximum count of harbor seals (1,900 animals) made in August 1979 represents an unknown proportion of the actual total population level of this species in the study area. An unknown number of animals were either in the water; foraging away from haul-out sites; not counted on the haul-out site (obscured by natural obstructions or other animals); and/or some active haul-out site(s) may have been missed. Recent investigations in areas outside our study area have examined this question of sampling thoroughness through the use of tagging or radio telemetry (Summers and Mountford, 1975; Pitcher and Calkins, 1979; Brown, 1980). These authors suggested that perhaps only 50% of a local harbor seal population may be hauled out at any one time. Brown (1980) estimated that the actual harbor seal population level in Netarts Bay, Oregon varies from 1.5 to 3.0 times the observed level.

Even if the physical habitat had been adequately subdivided, substantial variation in sample means may have arisen from inadequate replicate number or incorrect sample area. For benthos, major problems arose from low replication. Sample area may have been inappropriate as well. No new information was gathered at the outset of these baseline surveys to decide what sample area and levels of replication should be used. Methods in current usage derived from literature were the main sources of sample design, but the success of this approach has not been investigated. Bird surveys were conducted using many concurrent census techniques, but their relative efficacy has not yet been analyzed. The estimation of numbers taken from airplane censuses versus boat censuses, for example, could be compared if censuses were taken by both methods simultaneously. Degree of replication is probably lower than optimum for both bird and fish surveys, judging from the sample standard deviations.

Errors in species identifications or differences in taxonomic effort from year to year probably constitute the biggest difficulties in relying on benthic data. Outright errors are probably less common than inconsistent level of identification, since strong efforts were made to ensure reasonably competent identification. Consultation with experts on difficult groups was sometimes done, and some groups were not identified further than major taxon if it was thought that errors would be unavoidable. However, routine independent cross-checking among investigators was not done, which is valuable in catching errors.

Fish, bird, and mammal identifications were generally reliable, especially since relatively few species were involved. However, bird identification is sometimes made difficult by adverse viewing conditions, such as bad weather or glare. There are also variations between observers in their ability to identify and estimate numbers of birds.

IV. A. 3. e. (3) Natural unpredictability.

Variation due to natural unpredictability may arise from many causes, but the result is that the sample means are skewed or they have some nonnormal distribution. As a result, the use of parametric statistics in hypothesis testing becomes much less reliable than would be desirable.

One major contributor to this variation is the nonrandom distribution of individuals within a treatment group. A treatment group consists, for instance, of samples from one elevation in one season, or from one type of sampling gear in one season. None of the surveys included designs which tested for nonrandom spatial distribution. Nevertheless, nonrandomness was obviously common. It is easiest to see this in mobile species which form flocks or schools, but benthic species may exhibit aggregation as well. The high variation in tow net catches probably was largely due to schooling species, such as Pacific herring. Often, either a large number was caught when schools were encountered, or none (or few) were present. For benthic species, the degree of aggregation or patch size was not measured for even the most abundant species, as it was outside the scope of basic survey work. It is, therefore, impossible to tell if variation was due to patchiness or to low replicate number. For some abundant species, the coefficient of variation was less for individual strata than for all strata combined. This trend could be taken as an indication that within homogeneous conditions, variance is lowered. Interpretations should be made cautiously, however.

Another factor, especially in the estimation of year-to-year variation, is the breeding or recruitment success of the species under consideration. In the benthic data there are indications that in some years, some species had much better reproductive success than in other years. This observation was not consistent for all species in the same year.

Table 4 shows several examples of mean abundance and variability for selected benthic species as measured by the coefficient of variation (CV) at the -1 foot level in summer. These examples illustrate the kinds of variation to be expected in benthic baseline data. In example 1, mean numbers of the barnacles, *Balanus glandula*/*crenatus*, are shown for several rock and cobble habitats. Summer samples taken at -1 foot MLLW are used to aid in comparison. Data are missing for several of the sites, but 1976 appeared to be a particularly successful year for barnacles at Cherry Point. While at Tongue Point, an exposed rock habitat, barnacle numbers were much greater in 1977 than in 1976. Barnacle numbers at Cherry Point were much lower in 1978 and 1979 than in 1976, indicating that 1976 was an unusually good year at this site. At Cantilever Pier, a protected rock habitat, many more barnacles were present in 1977 than in 1978; and the CV was smaller in 1977 than in 1978. Cherry Point had lower numbers and a higher CV for barnacles in 1978 than in 1979, indicating that conditions for barnacle survival were poorer in 1978 at this site as well. Partridge Point, which is another cobble beach, had very few barnacles in any of the summer sampling periods. Note also that the CV decreases as the means increase within all the sites, which is a weak indication that barnacles are not aggregated in spatial distribution.

Example 2 shows that for Fidalgo Head, a protected rock habitat, *Balanus cariosus* was quite abundant and was less patchy than *Balanus glandula*. *B. glandula* was rare at this site in the summer of 1976.

Example 3 shows that the polychaete *Cirratulus cirratus* had comparable abundance and CV in 1978 and 1979. The species was less numerous at

Table 4. Examples of mean abundance and coefficients of variation for selected invertebrate species at several intertidal sites in summer. Means normalized to 0.25 m^2.

Species	Site	Elev.	1976 $\bar{X}$	1976 CV	1977 $\bar{X}$	1977 CV	1978 $\bar{X}$	1978 CV	1979 $\bar{X}$	1979 CV
Example 1										
Balanus glandula/crenatus	Partridge Point	-1'			0		0.3	1.2	10.0	0.9
	Cherry Point	-1'	21210.0	0.3			6715.0	0.6		0.2
	Cantilever Pier	-1'			976.0	0.9	1.8	1.6		
	Tongue Point	0'	22.0		4197.5					
Example 2										
Balanus glandula	Fidalgo Head	-1'	4.0	1.3						
Balanus cariosus	Fidalgo Head	-1'	1293.0	0.7						
Example 3										
Cirratulus cirratus	Partridge Point	-1'					48.0	0.7	13.8	1.8
	Cherry Point	-1'					178.5	0.5	113.5	0.5
Example 4										
Scoloplos sp.	Fidalgo Bay	+1.5'					190.0	0.3	45.5	0.6
Oligochaeta	Fidalgo Bay	+1.5'					3760.0	0.4	9.0	0.9

Partridge Point than at Cherry Point in both years, and was more variable in numbers in 1979 than in 1978.

Example 4 shows that strong year-to-year variations also occurred in homogeneous habitat types. At Fidalgo Bay at the +1.5' elevation in summer, the polychaete Scoloplos sp. showed a mean count in 1978 that was four times higher than in 1979. The CV in 1978 was half as large as that in 1979. Oligochaetes were about 400 times more abundant in 1978 relative to 1979, but the CV was only about half as large in 1978 as in 1979.

Published information on variations in species abundances indicates that differential settlement as well as differences in successional stage occur in a range of habitat types. Eagle (1975) observed patchy but stable communities having different dominant species in subtidal soft substrates in Liverpool Bay. He hypothesized that these arose from the timing of catastrophic storms. Species more abundant at the time of a storm as larval forms differentially colonized patches disturbed at different times. Differences in successional stage, as described by Lubchenko and Menge (1978) for rocky intertidal habitats, may also contribute to high variation about estimated mean abundances when random sampling design is used.

Variation in the abundances of benthic species might be expected to result in variation of prey spectra of opportunistic bottom-feeding fish. Miller et al. (1980) showed that the percent prey overlap, as measured by Sanders' Index of Affinity on I.R.I. values, is not particularly high for several benthivorous species. For example, at Port Williams in summer, tidepool sculpins apparently switched from gammarid amphipods as a major prey item in 1977 to harpacticoid copepods in 1978. The abundance of prey and their rates of production are unknown for this time period, and preferences for different prey items in tidepool sculpin are unknown.

Variations in fish species importance in the Strait sites were presented in several different ways by Miller et al. (1980). The rank order of species abundance, biomass, and frequency of occurrence of the 10 most common intertidal fish species show that changes in rank order occurred for all three parameters. These changes were due to the occasional capture of schooling species, such as smelt or herring, and also to the capture of large individuals of such species as spiny dogfish and pink salmon. Yearly variation in exposed sand sites may also be partly due to a large year class of speckled sanddab in the Strait of 1978. Some regional variation was noted as well. The Strait sites had significant numbers of sand sole and redtail surfperch which were absent from collections in northern Puget Sound. Schooling species generally ranked higher in tow net collections in northern Puget Sound than in the Strait.

The variation of site data was presented by calculating the probability that specified decreases in population density or biomass would actually be detected. The probability of detecting a 50% decrease in numbers or biomass in beach seine samples was rather low in general, but was reasonably high at Twin Rivers and Morse Creek for some seasons. The probability of detecting a 75% decrease in numbers or biomass was generally high, except in spring. A 90% decrease in biomass could usually be detected with a probability of over

90%, except at Jamestown in the spring, where the probability was still less than 50%. The probability for detecting such a decrease in numbers was somewhat higher at this site, however. For tow-net data, even a 90% decrease in biomass or numbers could not necessarily be detected with a probability of 50% or more. Even a 95% decrease in numbers still resulted in low probabilities of detection in some cases.

These data indicate a rather high degree of variation in all samples. The ability to predict decrease in populations is also apparently not as good as one would hope for. One of the assumptions of the power analysis is that the variance in the reduced population would be the same as that in the original population. The variance of baseline data is increased in large part by the schooling species, and also by the presence of aggregated larvae and juveniles. A decline in population would likely decrease the variance, since the degree of aggregation would not be the same.

For bird species, the coefficients of variation ranged from about 0.5 to 4. Values for the most abundant species commonly were in a range of 1 to 2. Problems inherent in habitat definition and sampling design no doubt played a part in the observed variation. For the currently defined intertidal/subtidal habitat types, coefficients of variation were generally lower in the protected mixed fine category than in other habitats. These areas also harbored the largest mean numbers of individuals. In the case of birds, it is important not to discount the validity of data simply because of high variances. Migrations of large numbers of individuals over relatively short time spans is one of the major features of shallow water areas. Data should be examined for patterns which account for the observed variation. This is also true when examining data on the other taxa.

Since mammal species were not censused using a habitat approach, little can be said about variation in habitat usage. However, habitat types were noted at major hauling out sites for pinnipeds. There does seem to be a clear preference for rocky islands or gravel beaches as haul-out areas, but this trend may relate more to factors of disturbance and proximity to abundant prey than to substrate preference. As with birds, total counts of some mammal species varies widely with time due to their migratory habits.

IV. A. 3. e. (4) Observed variation within and between habitat types.

Rock/cobble habitat: Numbers of benthic species showed a decrease by a factor of 10 from the -10 m depth to the +6' level for all the sites. Wet weights of plants and animals at these sites were on the order of 100 to 1000 g/m at the +3' and 0' levels, and on the order of 10 g/m at the +6' level. Macroalgae and barnacles predominated in terms of biomass at the rock-cobble sites except for Partridge Point. This site had very low numbers of barnacles. Cherry Point, another cobble site, consistently had enormous numbers of barnacles. This difference was probably due to differences in grain-size profile. The relatively small, uniform cobbles at Cherry Point may be too unstable for macroalgae or may not provide suitable stable crevices for barnacle-eating predators to lurk in during low tide. The subtidal substrate at this site grades to mixed fine sediment rather quickly;

while at Partridge Point, the subtidal substrate is similar to the intertidal cobble substrate.

Fish species richness in rock and cobble habitats increased with increasing substrate stability. Tidepools in rock outcrops generally supported more species than did tidepools in cobble beaches. Variability in net samples was rather high, but rank order and frequency of fish species were relatively consistent.

Dominant bird species in rock-cobble habitats included both those species which are fairly habitat-specific and those that are not. The Black Oystercatcher and the Harlequin Duck were consistently present in low numbers in rock habitats. The CV for these species is quite high, which is probably a result of difficulty of detection as well as patchy use of habitat. Surf Scoters and Glaucous-winged Gulls were widespread in other habitat types in addition to the rock-cobble areas. These species used the areas both for roosting and for occasional feeding. The variation in abundance might relate both to patchy use of the habitat and to cyclic activity patterns not accounted for in the sampling design. For example, the presence of offshore tide rips nearby may make some rocky outcrops or cobble beaches more attractive as roosting sites than other areas which superficially look identical.

Exposed unconsolidated habitat: Two main patterns of benthic species richness, biomass, and density with elevation were observed at the exposed unconsolidated sites in the study area. Where the subtidal substrate was relatively stable cobble, as at Ebey's Landing and Guemes Island South, biomass and abundance were usually higher below +0' than above. However, during some seasons, even the intertidal elevations had high densities and biomass, possibly due to seasonal growth of scavenging or detritivorous species. At Ebey's Landing, amphipods were abundant in spring and summer and at Guemes South isopods were abundant in summer to fall. At other exposed sites, the intertidal zones had uniformly low occurrence and abundance of benthic species. The subtidal substrate graded to mixed sand and pebble in these locations. While there was an increase in species richness and abundance at tidal elevations, it was not nearly as great at sites where cobbles were present in subtidal zones. Subtidal cobble habitat in these exposed locations may be somewhat less stable than areas with less sediment transport. For instance, at Ebey's Landing in winter of 1977-1978, one subtidal elevation was inundated by sand. The species found there were closely similar to those found at West Beach, a site on Whidbey Island which had sand in the subtidal area.

Exposed sites were characterized by high variation in fish catches due to the effects of capturing schooling species. There was substantial between-year variation in seasonal catches as well. This variation could be due to differences in year class success, but no conclusive evidence is available.

Birds in exposed sites were often roosting or migrating, but some species possibly were also feeding there, especially when migrating or schooling fish were present. The variation in mean abundance probably resulted from both feeding and migration, as well as from local weather and tide conditions. As at all areas in the Puget Sound region, migration resulted in lower species richness in the summer than in other seasons; but resident breeding species, such as the Glaucous-winged Gull, often were abundant. Variation in density of the resident species probably depended on proximity to breeding colonies, but the presence of juveniles in nonbreeding areas may have negated this effect.

Protected unconsolidated habitat: Protected sites with unconsolidated sediments showed substantial variation in benthic species richness and abundance with elevation and season. Species richness decreassed most strongly above the +3' to +5' level in the intertidal zone at all the sites. This trend may not reflect actual differences in community organization, however. Benthic biomass was much lower at the +6' elevation than at lower elevations, unless rock or gravelly substrates were found at this elevation. Fidalgo Bay had rock outcrops in the high intertidal zones, which supported some algae and barnacle growth. At Birch Bay and Drayton Harbor, the +6' level had high mean biomass due to the extremely patchy occurrence of eelgrass. Biomass was generally highly influenced by the occurrence of large bivalves. Density varied between sites in unpredictable ways. The high elevations were often dominated by small oligochaetes and polychaetes. Even at the mid- and low-intertidal elevations, the sites did not show very similar mean abundances. Polychaetes, oligochaetes, and amphipods were typically important groups, but the abundances of these groups were not particularly similar across all protected mixed fine sites. For example, the low elevation at Jamestown and Birch Bay differed in mean count by a factor of 10, as did the low elevations at Beckett Point and Webb Camp.

Variability in fish abundance at the protected sites was again largely due to capture of schooling species. Abundance and species richness were consistently high in these habitats as compared to most other areas.

Dominant bird species showed relatively small variability within seasons in the protected habitats. Seasonal variation is large due to migrations. In the fall, winter, and spring, when seasonally resident species were numerous, coefficients of variation were relatively low for the dominant species.

Mammals using mudflats as haul-out areas were less numerous than they were at other areas. Some sites, such as Padilla Bay, were consistently used; while others, such as Lummi Bay, were apparently not. Disturbance could have caused some of these differences, but this factor was not measured routinely.

IV. A. 3. e. (5) Summary.

This analysis may seem to indicate that much of the baseline data are unreliable for hypothesis testing. While this conclusion may be true for data examined on a yearly basis, the data for each season and, for benthos, data further segregated by specific elevations are generally less variable. Dominant species, as defined by relatively high biomass or numbers, were also often less variable in their abundance than the less abundant species.

In assessing the impact of some perturbation on a given location, careful attention should be given to defining the habitat. Although not tested experimentally, using appropriate subsets of baseline data as being representative of sites not sampled might be fairly reliable. However, one must be particularly wary of interpreting differences in mean abundances without considering the degree of variation about those means.

IV. B. Nearshore Waters

IV. B. 1. Habitat definitions. The nearshore water habitats include the water column from the high tide line offshore to the 20 m (~60') depth contour. This 20 m depth contour was selected as the dividing line between nearshore waters and offshore waters (Section IV.C) in part because several of the various investigations used this as an outer boundary for their study, and also because observations (of birds, for example) very often indicated species composition and abundance of biota changed at about the 20 m isobath. Animals and associations described in the following sections are those within the water column itself, while those more directly associated with the intertidal and subtidal substrates were discussed under the preceding section.

While the nearshore water column communities differ among themselves less than those of their various adjacent intertidal/subtidal communities, they do not represent one homogeneous type. We, therefore, differentiated communities, where data permitted, between nearshore waters over rock/cobble, protected unconsolidated sediments, and exposed unconsolidated substrate types, as described in Section IV.A.1.

Though the nearshore waters represent a small fraction of the total water surface area of the study area (see section IV.B.2, below), their use as spawning, nursery, and feeding areas suggests an importance inverse in proportion to their limited area or volume. It is likely they also provide a substantial part of the zooplankton which later inhabit offshore waters and support communities there.

IV. B. 2. Spatial extent. The extent of the nearshore area is estimated in Table 5. Much of the shallow water area occurs along the open shorelines and adjacent embayments of the Strait of Juan de Fuca, eastern Strait of Georgia, and in the bays of Whatcom and Skagit counties. The narrow shelves along passages and around islands represent a relatively small part of the total.

IV. B. 3. Major Biological Assemblages.

IV. B. 3. a. Community composition. This section deals with the mammals, birds, and fish using this neritic area and not directly associated with the bottom. Most feed exclusively within the water column. Many spend only a part of their life cycle or a part of each day in this zone.

The birds and mammals are primarily fish-eaters, and include a number of species which feed on bottom-associated fish as well as mid-water prey. Thus, many of these predators are partly dependent upon the productivity of the shallows.

Table 5. Extent of nearshore and offshore waters within the study area*

	Estimated Area in km^2		
	Nearshore (<20 m)	Offshore (>20 m)	Total
A. Bays			
Discovery Bay	10	20	30
Bays in Whatcom-Skagit Counties	155	180	335
Bays in San Juan Islands	70	30	100
B. Passages			
Northern Admiralty Inlet	15	60	75
Bellingham Channel	5	70	75
Haro Strait	15	550	565
Rosario Strait	20	280	300
Northern San Juan Waters	5	150	155
Passages in San Juan Islands	20	130	150
C. Open Waters			
Strait of Juan de Fuca	300	3,500	3,800
Eastern Strait of Georgia	140	420	560
Western Strait of Georgia	20	360	380
	775	5,750	6,525
	(12%)	(88%)	

*Boundaries and areas derived from Wahl et al. (1981).

A relatively abrupt change in species composition, richness, and numbers occurs at about the 20 m depth as exemplified by the birds (Table 6).

The nearshore area is the principal foraging habitat of the harbor seal, which presumably feeds in bays and along shorelines of all types. Those pinnipeds described previously as hauling out on intertidal rocks and beaches seek refuge from disturbance and forage for fish in nearshore waters.

The only cetacean that can be considered nearshore is the harbor porpoise, though they may occur in offshore water also. They appear in nearshore waters most commonly in spring and summer. Other local cetaceans are capable of entering the nearshore areas while transiting to other areas or while foraging or in pursuit of offshore prey, but these movements are unpredictable. It is reasonable to expect that any of the cetaceans common to the study area (gray whale, minke whale, killer whale, Dall porpoise, and harbor porpoise) can on occasion be found in the nearshore areas.

Nearshore waters also support a large proportion of the fish-eating marine birds which occur seasonally within the study area, including a number of species of loons, grebes, cormorants, mergansers, gulls, and alcids. Appendix Tables III-I to III-P list the most frequently occurring bird species seasonally within the eight nearshore habitats. Allowing for seasonal differences, these lists are remarkably similar. Twelve of the 21 species occurred (as one of the 10 seasonally most-frequently observed species) in all eight habitats, and five more species occurred in at least six habitats. These species are all either obligate fish-eaters (loons, grebes, cormorants, mergansers, Common Tern, and nearshore alcids) or gulls which eat many things including fish. While other species occurred seasonally within these water-column habitats, numbers were relatively small. Most of the obligate fish-eaters in the nearshore group occurred almost strictly within the nearshore waters. Mergansers, for example, seldom were observed feeding in water of greater than 20 m depth.

The most common birds varied seasonally at exposed habitats and from place to place, though the gulls were always abundant. In the protected habitats grebes were abundant in nearshore waters over mud-gravel habitats and Pigeon Guillemots occurred consistently at mud-sand habitats. Large numbers of Double-crested Cormorants at protected mud habitats reflected the observations of many of these birds commuting daily to forage in the shallows of Padilla, Samish, and Fidalgo Bays. Marbled Murrelets occurred consistently in low densities at exposed rock; Pigeon Guillemots in large numbers foraged off exposed rocks in the summer. Protected rock habitat was important to Pigeon Guillemots and Marbled Murrelets year-round, Common Murres in the fall, and Pelagic Cormorants in the summer.

Birds found in these nearshore habitats showed greater mobility than bottom- or benthic-feeding species which foraged on shellfish or eelgrass, for example, and which normally show relatively stable seasonal distribution patterns. On the other hand, the neritic fish-eaters appear to show more consistent patterns of distribution than their counterparts in the offshore waters (Section IV.C).

Table 6. Predominant distribution of commonly occurring bird species feeding within nearshore and offshore water columns (maximum seasonal densities from Appendix Tables III-I thru III-P)

Nearshore (<20 m)	Offshore (>20 m)
Common Loon	Arctic Loon
Red-throated Loon	
Red-necked Grebe	Western Grebe
Horned Grebe	
Double-crested Cormorant	Brandt's Cormorant[1]
Pelagic Cormorant	
Red-breasted Merganser[2]	
Glaucous-winged Gull	
California Gull	
Mew Gull	
Bonaparte's Gull	
Heermann's Gull	
Pigeon Guillemot	Common Murre
Marbled Murrelet	Ancient Murrelet[1]
Rhinoceros Auklet[3]	Tufted Puffin[1]

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[1] Did not occur (as one of 10 most-frequently occurring species) in nearshore habitats.

[2] Did not occur in offshore habitats.

[3] Highest nearshore densities due to feeding flocks along shorelines adjacent to offshore area--often more widespread offshore.

Both the MESA and WDOE nearshore (tow nets) fish sampling schemes were patterned on the intertidal habitat classification; i.e., sampling sites were at the various exposed, protected, unconsolidated, and rock substrates as observed at low tide. The original idea was to investigate whether the nearshore pelagic fish assemblage reflected a dependency on the intertidal habitat communities. However, in both the Strait of Juan de Fuca and northern Puget Sound, no strong correlation was found between the defined intertidal habitats and the composition of the nearshore pelagic fish community. Consequently, the decision to consider the nearshore water as a single distinct habitat appears appropriate and useful in the case of fishes.

Although the method of sampling neritic fishes was highly variable, the general results were quite consistent for both the Strait of Juan de Fuca and northern Puget Sound (Table 7). Pacific herring larvae and juveniles were the single most important species in terms of percent occurrence, abundance, and biomass. Other important neritic species (but clearly of secondary importance to herring) were surf smelt (all life history stages); longfin smelt (juvenile and adults); Pacific sand lance (all life history stages); juvenile chum, pink, coho, and chinook salmon; juvenile tomcod and walleye pollock; and tadpole sculpin (all life history stages). The one obvious difference between northern Puget Sound and the Strait of Juan de Fuca was the absence of three-spine sticklebacks from the Strait samples. Those species (except herring) that often ranked highly in percent occurrence usually ranked highly in abundance also, but low in biomass (e.g., surf smelt). Conversely, some species such as spiny dogfish ranked second or third in biomass but relatively low in occurrence and abundance. Some 29 species from the Strait were included in this ranking scheme, while only 17 were included for the northern area.

Although there was no association with specific intertidal habitats, longfin smelt, and threespine stickleback were most abundant in areas of freshwater inflow which presumably were also spawning sites for these freshwater spawning species. Of course, salmon are also freshwater spawners and when they first come out of the rivers and streams to the saltwater, they are concentrated in those areas; but since they migrate to the open ocean there are juvenile salmon throughout northern Puget Sound and the Strait of Juan de Fuca. In addition, the studies of nearshore fishes indicated that protected embayment areas harbored larger quantities of these fishes which stayed longer through the year (i.e., they appeared sooner in the spring and left later in the fall).

Pronounced seasonal changes were evident from all data collected on nearshore species (species composition, abundance, biomass, and length frequency). By winter almost the entire neritic fish assemblage had moved away from the shoreline, presumably to deeper water, except in the case of salmon, at least some of which may have made it to the open ocean. Pacific herring larvae predominated in spring, herring juveniles predominated in the summer, but by fall herring juveniles had left the nearshore waters.

In summary, although the diversity of fish species in the nearshore habitats was low, the habitats appeared to be critically important as nursery

Table 7. The 10 most common neritic fishes of northern Puget Sound and the Strait of Juan de Fuca ranked according to occurrence, abundance, and biomass, 1974-1979.

Northern Puget Sound Species	Occurrence		Abundance		Biomass	
	1974-1975	1975-1976	1974-1975	1975-1976	1974-1975	1975-1976
Pacific herring	1	1	1	1	1	1
Threespine stickleback	2	2	2	3	3	8
Pacific sand lance	3	3	3	2	8	3
Surf smelt	4	4	5	5	9	
Pacific staghorn sculpin	5	6	7		5	5
Chinook salmon	6	7	10	9	7	6
Tadpole sculpin	7	10	4	7		
Longfin smelt	8	5	9	4		7
Chum salmon	9					
Soft sculpin	10					
Shiner perch			6	10	6	
Pacific tomcod			8	8		
Spiny dogfish					2	2
Starry flounder					4	4
Coho salmon		9			10	9
Northern anchovy		8				10
Snake prickleback				6		

Continued

Table 7. (Contd.)

Strait of Juan de Fuca Species	Occurrence			Abundance			Biomass		
	76-77	77-78	78-79	76-77	77-78	78-79	76-77	77-78	78-79
Pacific herring	1	1	1	1	1	1	1	1	1
Surf smelt	2	5	3	5	4	3	9	7	
Tadpole sculpin	3	3.5	5	7	9	5			
Crescent gunnel	4	11	5.5		10				
Pacific sand lance	5.5	2	2	8	3	2		5	
Walleye pollock	5.5			4	8				
Longfin smelt	7			2	2		4	2	
Tubesnout	8	5.5	5.5	9		6		6	5
English sole	9			10					
Shiner perch	11.5	5.5		3	5	8.5	2	4	
Pink salmon	11.5								
Northern anchovy	11.5	7.5	4		7	4			
Manacled sculpin	11.5	7.5							
Pacific tomcod		3.5		6	6		7	10.5	8
Spiny dogfish		11				9.5	3	3	2
Starry flounder							5		4
Coho salmon							6		
Pile perch							8		
Striped perch							10		
Chinook salmon		11	9		9.5			8	10
Pacific staghorn sculpin								9	
Wolf eel								10.5	
Kelp greenling									3
Threespine stickleback		9							
Sailfin sculpin			9						
Widow rockfish			6.5			7			7
Chum salmon			9			8.5			6
Bay pipefish			6.5						
Pacific sandfish									9

areas for some economically and ecologically very important fishes--i.e., salmon, herring, smelt, sand lance, and cod fishes.

IV. B. 3. b. Trophic organization. The problems concerning a lack of trophic structure data as outlined above for the intertidal/subtidal habitats also apply to the nearshore habitats. Very little is known of energy flow in nearshore habitats. Some information exists for adjacent habitats in the southern Strait of Georgia and the Puget Sound central basin. For example, Parsons et al. (1969a and b) provided phytoplankton information for the water masses under the Fraser River plume in the Strait of Georgia between February and May 1967. It was used to approximate the nearshore situation because of the mixing and nutrient characteristics. Complementary data on chlorophyll *a* in that region were also surveyed (Stephens, 1968) and transformed to a total organic weight value by a C/Chl *a* ratio of 30 (Strickland, 1960) and a carbon proportion of 50% of total weight. These values were also compared with Parsons et al. (1970) and Stockner et al. (1979) in their summary of plankton production in that region. Offshore standing stock of phytoplankton was estimated from Chester et al. (1980) and Mackas et al. (1980) in the same manner for chlorophyll *a* measurements in the middle of the Strait of Juan de Fuca.

Herbivorous (suspension-feeding) and carnivorous zooplankton of offshore and nearshore neritic habitats have also been poorly documented. Similar to the primary production estimates, data on zooplankton within the Fraser River plume (Parsons et al., 1969a, 1970) were used as an estimate of the nearshore standing stock and data from the center of the Strait of Juan de Fuca (Chester et al., 1980; Mackas et al., 1980) were used, in conjunction with data from selected stations in the southern Strait of Georgia (Robinson et al., 1968a and b; Barraclough and Fulton, 1967, 1968; Barraclough et al., 1968; Barraclough, 1967a and b; Robinson, 1969) to estimate zooplankton standing stock for offshore habitats.

The trophic organization of the nearshore zones did not appear to be habitat-specific. All the organisms were swimmning or floating. The majority were highly mobile and were not closely associated with underlying benthic habitat types. Therefore, the following discussion applies broadly to all nearshore areas; and because much of the data were available only from offshore (>20 m) waters, it also applies somewhat to offshore habitats discussed in further detail in Section IV.C. below.

The food web structure characterizing the neritic zone adjacent to the shore (Figure 23) was basically a condensed version of the offshore habitat group. Nearshore habitats supported biological communities similarly based upon phytoplankton production, suspension-feeding hervivorous zooplankton, carnivorous zooplankton, planktivorous fishes and birds, and piscivorous fish, birds, and marine mammals. Production, at least in terms of standing stock, appeared to be measurably higher than in offshore waters.

The taxa dominating these food web nodes also tended to be the same as those offshore but with some exceptions. Deep water herbivorous calanoid copepods (i.e., *Calanus*) which were important offshore did not appear in equal density nearshore. Epibenthic forms, such as omnivorous mysids, entered the community from the adjacent epibenthic communities and contributed to the diet of neritic zooplanktivorous fishes. The schooling neritic fishes, particularly Pacific herring and Pacific sand lance, also were more common in these habitats and, consequently, constituted major prey resources for the piscivorous fishes and birds in the community. As in the offshore habitats, loons and grebes, particularly the Western Grebe and Arctic Loon, were the dominant piscivores; but the Common Murre also often comprised a large proportion of the total standing stock of piscivorous birds.

The role of piscivorous marine mammals in energy flow is poorly understood and has not been quantified in the area. Killer whales, however, have been known to consume pinnipeds, flatfish, cod fishes, salmon, and squid. Harbor porpoise apparently eat schooling fishes, such as herring. Harbor seals are known to consume a wide variety of fish, including cod fishes, osmerids, and sea perch. They occasionally eat octopus also. Whiting (hake) and various bottomfishes apparently are important prey for sea lions.

Although structurally similar to the offshore food web, the nearshore food web supports a higher standing stock of organisms at most trophic levels and may reflect actual differences in production considering that the functional groups are essentially the same as in the offshore food web. There are a number of possible explanations for this apparent difference. First, unlike in the offshore habitats, surface-to-bottom mixing and estuarine plumes are typical of the nearshore habitats, especially in the vicinity of headlands (Pingree et al., 1978) which are common features of the region's shoreline. Second, adjacent shorelands and rivers provide immediate sources of nutrients which are mixed into the nearshore neritic water. Third, spawning populations of animals with pelagic larvae, whether nearshore, shallow subtidal or intertidal, release their progeny directly into the nearshore water column. A certain proportion of these migrate or are transported into offshore habitats; but the majority appear to feed, grow, and develop in the nearshore habitats where they form important prey and predator populations during that time. Two examples of such animals include the Pacific herring and Dungeness crab. Pacific herring spawn their demersal eggs in shallow subtidal habitats. Upon hatching the larvae soon begin schooling in neritic waters and typically aggregate in contained embayments through much of their larval and early juvenile life; during these stages they form high density congregations that feed upon small herbivorous copepods. They are, in turn, fed upon heavily by neritic fish-eating fishes and nearshore birds. During this period (April-July), the role of Pacific herring in the nearshore food web is pervasive.

Dungeness crab also release their pelagic larvae into nearshore waters, especially in contained embayments and estuaries, where they develop through the various larval stages. As zoea they are fed upon extensively by juvenile salmonids and other neritic zooplankton-eating fishes and are themselves carnivorous upon smaller zooplankton. In both cases, it would appear that a highly advantageous life history strategy is to release progeny into nearshore waters where primary and secondary production is measurably greater and less heterogeneously distributed than in offshore habitats.

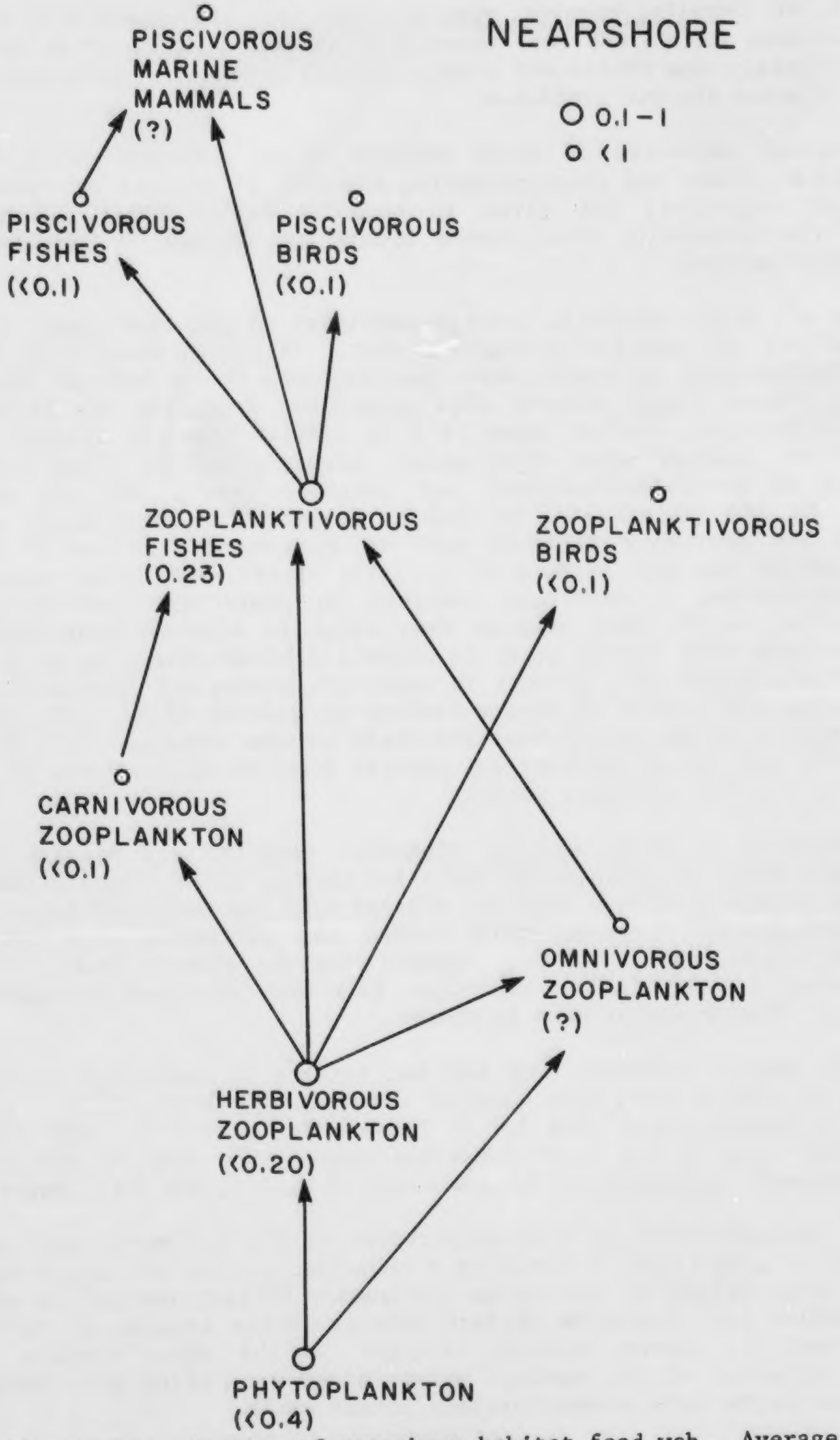
NEARSHORE
○ 0.1 – 1
o < 1
PISCIVOROUS MARINE MAMMALS (?)
PISCIVOROUS FISHES (<0.1)
PISCIVOROUS BIRDS (<0.1)
ZOOPLANKTIVOROUS FISHES (0.23)
ZOOPLANKTIVOROUS BIRDS (<0.1)
CARNIVOROUS ZOOPLANKTON (<0.1)
OMNIVOROUS ZOOPLANKTON (?)
HERBIVOROUS ZOOPLANKTON (<0.20)
PHYTOPLANKTON (<0.4)

Figure 23. Characterization of nearshore habitat food web. Average biomass of major taxa represented in parentheses(grams/m^2 or grams/m^3).

IV. B. 3. c. Density, biomass, species richness. The emphasis in the marine mammal studies was on the most observable species that could be quantified. Thus, primarily the hauled-out pinnipeds were counted. Equivalent data for nearshore areas are not available.

Seasonal densities of birds assumed to be associated with the water column (i.e., fish- and plankton-eating species, as opposed to those feeding on bottom organisms) are given in Appendix Tables III-I through III-P, listing the seasonally most common species which may be defined as the predominent species.

For all eight habitats, average densities ranged from about 13 to 396 birds/km^2 for all species during the year. If gulls, which also forage on intertidal/subtidal habitats, were removed, this range becomes about 2 to 102/km^2. These ranges compare with equivalent densities for corresponding intertidal/subtidal habitat types of 8 to 1280/km^2 for all species and 1 to 1142/km^2 for species other than gulls (Appendix Tables III-A through H). Densities of intertidal/subtidal and nearshore water habitats were more similar in the relatively low-density exposed unconsolidated and rock habitats and generally differed more in high-density protected habitats. This situation was most evident in the fall, winter, and spring seasons, when large populations of waterfowl resulted in protected intertidal/subtidal densities up to 20 times greater than those in adjacent nearshore waters. Densities were more nearly equal in exposed habitats where large numbers of fish-eating species were present in nearshore waters and subtidal/intertidal habitats had low numbers of bottom-feeding or grazing birds. The particular exception to this was cobble habitats where herring spawned. Scoters feeding on spawn in the intertidal/subtidal habitat resulted in densities of 10 to 20 times those of the nearshore waters.

Summations of total species richness, density, and biomass for each season are shown in Appendix Tables III-Q through III-T. During the spring, most bird groups were very similar; exposed sand and rock were lowest for all three parameters. Exposed mixed coarse and protected rock had highest densities and biomass in summer. Exposed rock was clearly lowest in density and biomass in the fall. Protected rock and protected mud-gravel were highest in density and biomass in winter.

Fish species richness for tow net catches in nearshore zones of the study area were surprisingly similar from site to site (Figure 24). Mean species richness ranged from 2.7 at Deadman Bay to 9.8 at Lummi Bay. Most mean values were in the 4- to 6-species range. The mean of the means for rocky, exposed, and protected habitats were 6.3, 5.7, and 7.4, respectively.

The maximum number of species occurred in the spring at most sites, or in summer at some sites, followed by a reduction in the fall and a minimum in winter. High values in the spring and summer reflect the influx of larvae and juveniles into nearshore surface waters. Sites sampled in the San Juan Islands had the fewest species relative to the other regions sampled. Samples collected at the eastern Strait sites were often more species-rich than those in the more exposed western Strait sites.

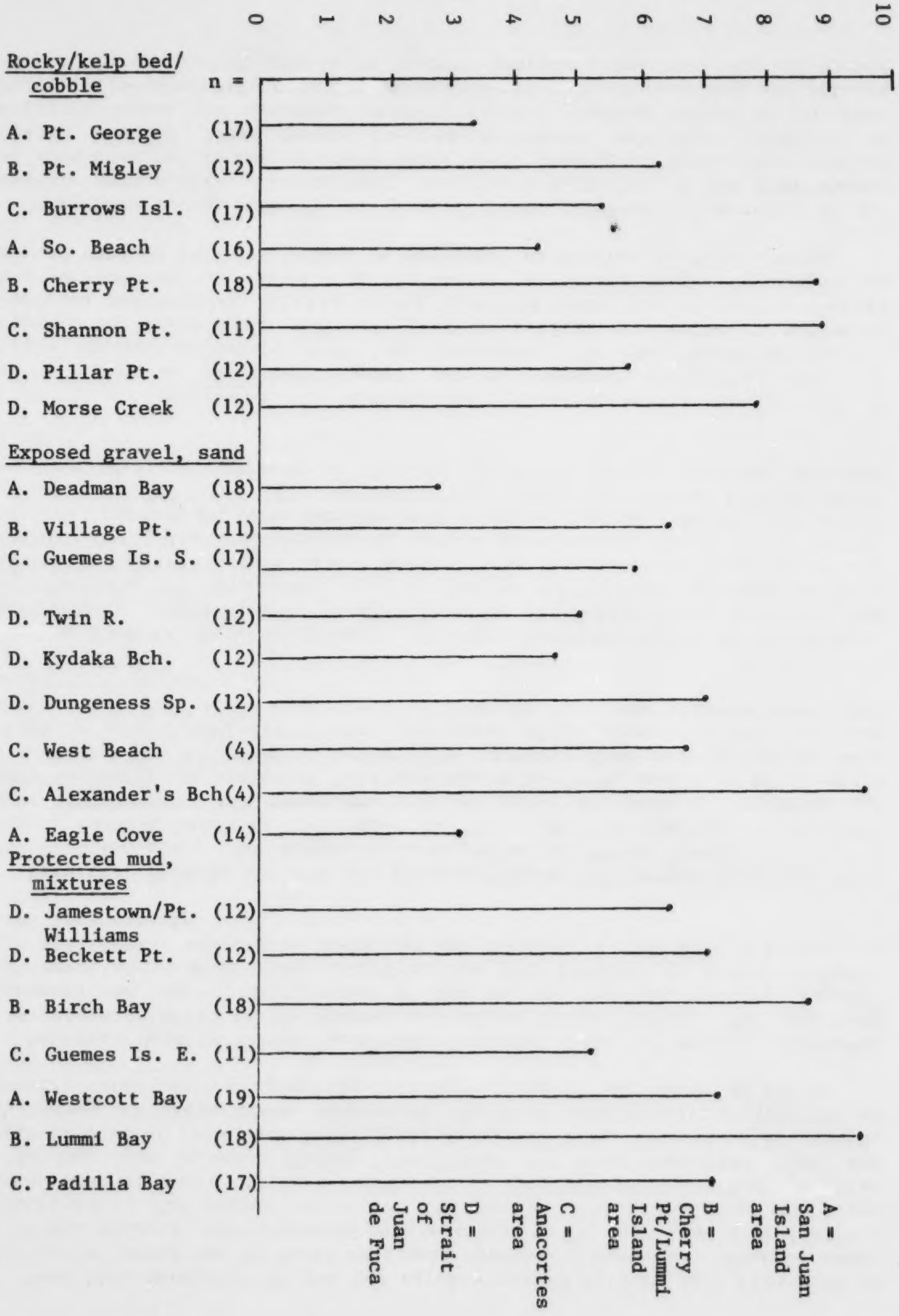

Figure 24. Mean species richness per pair of hauls for fish caught in tow-nets.

Mean fish densities in tow net catches varied between less than 0.01 to 0.52 fish/m among the 24 sites that were sampled (Figure 25). Mean of means for rocky, exposed, and protected habitats were 0.13, 0.05, and 0.06 fish/m , respectively. The higher value for the rocky habitat reflects the large catches made at Morse Creek, a cobble site. The mean of means for the sites in the San Juan Islands, Cherry Point/Lummi Bay area, Anacortes area, and Strait of Juan de Fuca were 0.09, 0.10, 0.03, and 0.15, respectively. Again, high values at Morse Creek influenced the high mean densities (due to an unusually large catch of juvenile Pacific herring in the summer of 1977).

Seasonal density trends generally followed those of species richness; maxima often occurred in the spring and minima in the winter. The schooling tendencies and patchy distribution of the species (Pacific herring, smelts, sand lance, etc.) most often caught in tow nets resulted in highly variable catch statistics, especially densities and biomass. Trends were difficult to define very clearly.

Mean fish biomass for tow net samples (Figure 26) ranged from less than 0.01 to 1.04 g/m ; the unusually high value at Morse Creek reflected a uniquely massive catch in the summer of 1977. Disregarding the Morse Creek summer 1977 sample, the range was 0.01 to 0.69. The mean of the means for rocky, exposed, and protected habitats was 0.08, 1.10, and 0.25 g/m , again disregarding the Morse Creek summer 1977 sample. Mean biomass values were highest in the Cherry Point/Lummi Bay area; while those for the San Juan Islands, Anacortes area, and Strait of Juan de Fuca were slighly lower, but similar to each other.

Mean biomass was often greatest in summer catches, lowest in the winter. Some tendency toward highest biomass in protected habitats was apparent, but this trend was not consistent as reflected by low biomass at Jamestown/Port Williams and Guemes Island East. Many of the lowest values occurred at the exposed sites. High variability in biomass data usually was a result of the occasional capture of large species such as spiny dogfish, various sea perch, flounder, and sculpin. The extremely high value for summer 1977 at Morse Creek reflects the capture of 120,000 juvenile Pacific herring weighing 300 kg.

IV. B. 3. d. Migrants. In describing typical movements in and out of nearshore waters, the term migrant may be somewhat misleading since it usually implies movements over long distances. In the nearshore waters, movements of animals in and out of this habitat may actually be quite restricted and involve animals moving into the water column during certain times of the day or season. A discussion of larger scale migrations as observed through offshore waters is described in Section IV.C.3.d. below.

Migratory marine mammals are generally not important components of the nearshore communities. During their northward migration, a few gray whales have been observed in the inside waters, often pausing to feed. This feeding activity usually takes place in the nearshore habitats, normally in mud-gravel areas and mud-sand areas. Typical feeding behavior for this species includes passing over the bottom on its side and scooping and sifting sediment through baleen plates to recover benthic organisms. Killer whales

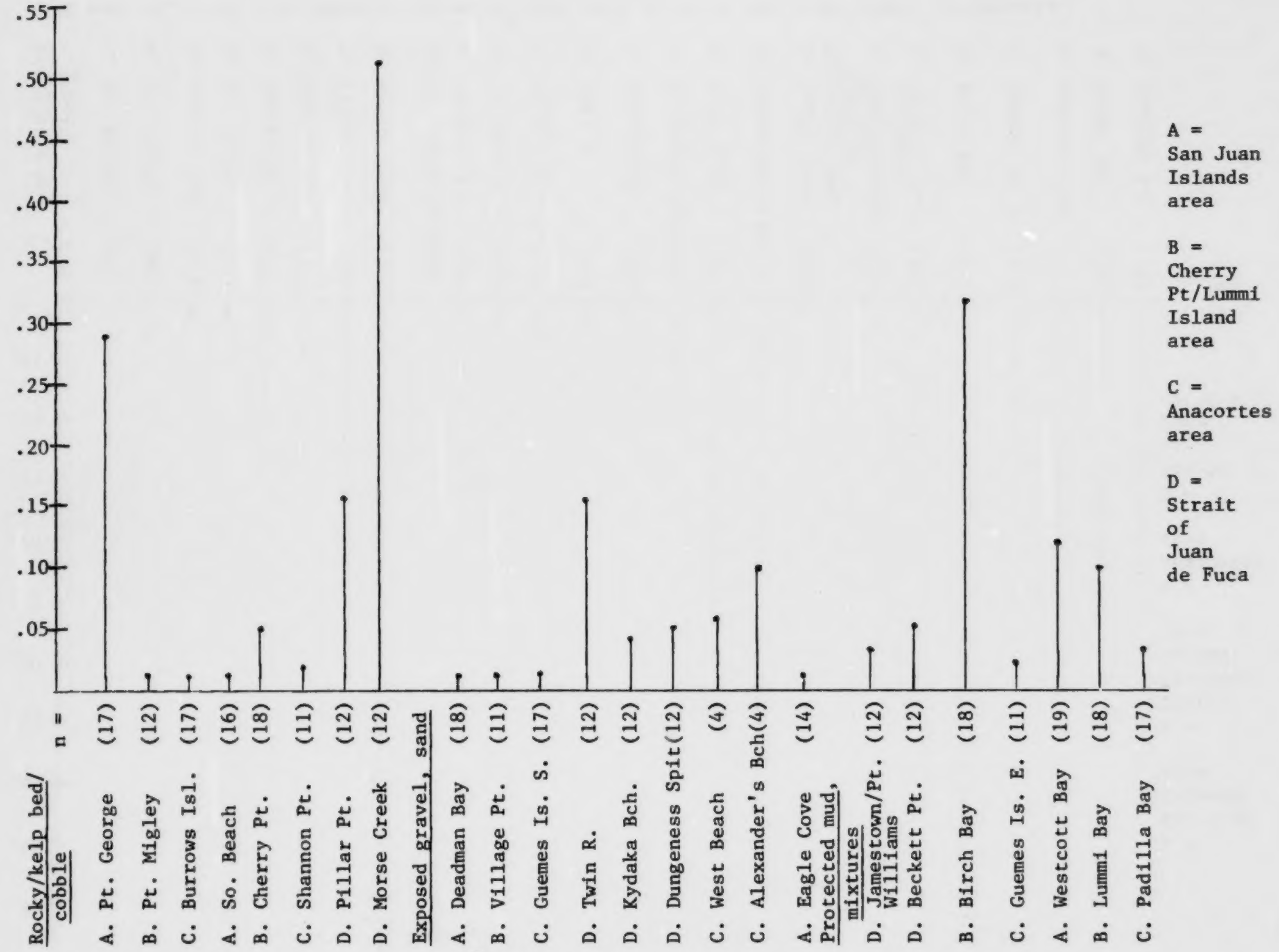

Figure 25. Mean fish density (No./m^3) per pair of hauls for fish caught in tow-nets.

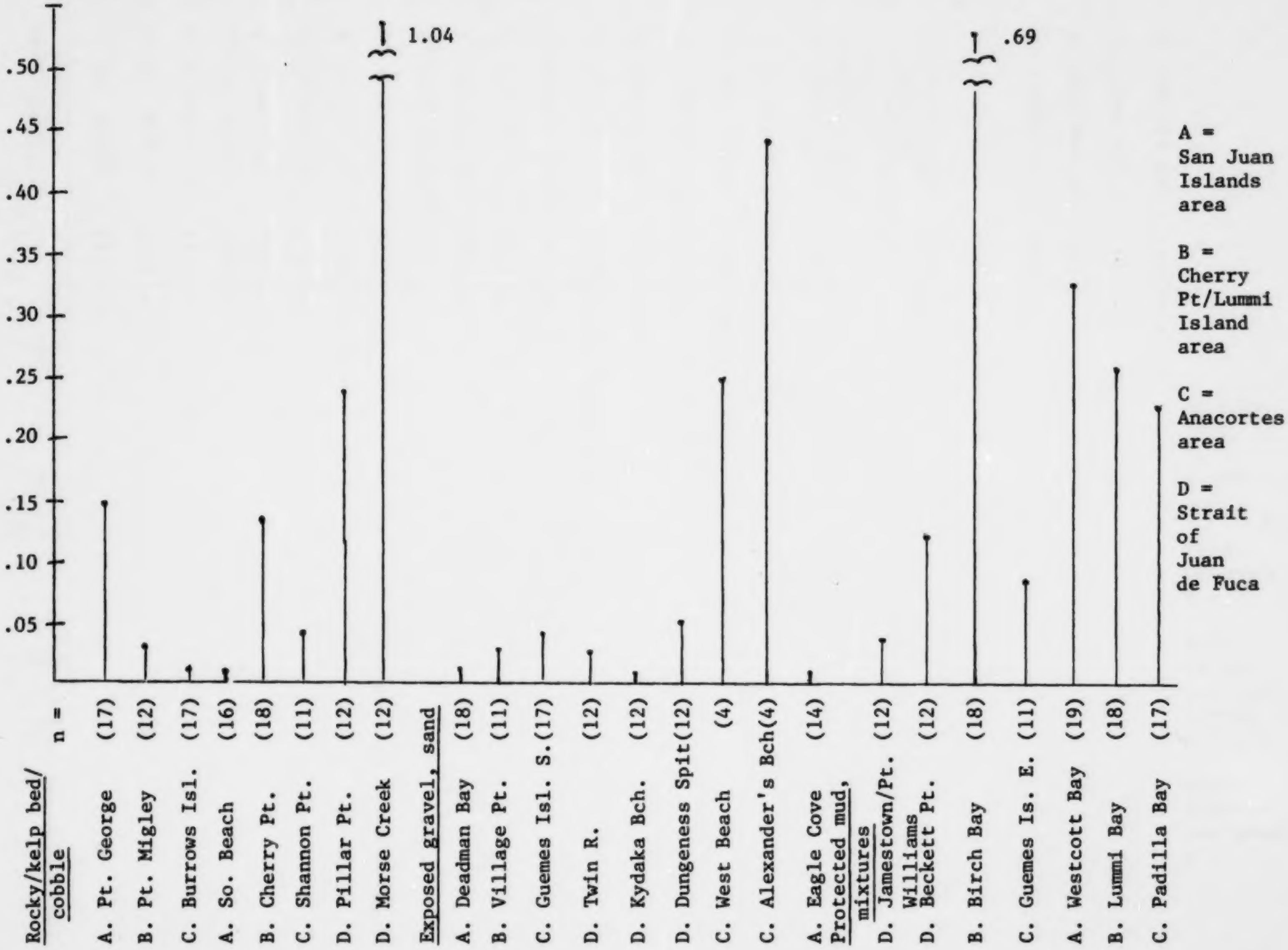

Figure 26. Mean fish biomass (grams/m^3) per pair of hauls for fish caught in tow-nets.

may occasionally frequent nearshore areas utilized by harbor seals. Presumably killer whales entering these areas forage upon pinnipeds and fish.

Both California and northern sea lions, which are migrants, pass through nearshore areas as they enter a haul-out area, but they are not considered to be important components of the nearshore community. They are primarily offshore and deep-water feeders.

Seabirds in the nearshore area exhibited movements that were similar to those found in offshore waters. Major movements of birds took place to and from inland nesting sites (occupied in the spring and summer) to wintering areas in the nearshore bays (e.g., Western Grebes). Other loons, grebes, cormorants, alcids, and mergansers also followed this pattern. Large flocks of gulls passed through the nearshore waters during migration seasons; and two species, Mew and Thayer's Gulls, were important nearshore residents.

Smaller scale movements of locally nesting birds, like the Common Merganser, to saltwater and the dispersal of species, like the cormorants, Pigeon Guillemots and Marbled Murrelets, to and from breeding areas occurred throughout the nearshore regions. Movements of the latter species were from breeding areas nearshore to foraging areas, often offshore. Glaucous-winged Gulls, the most abundant gull in the study area, also dispersed from areas around colonies to nearshore wintering habitats in August-September. Adults began to return to nesting colonies and establish territories as early as January or February, though most juveniles remained away from the colony all year.

Based on density information from Appendix Tables III-I through III-P, the greatest densities of birds were observed in the spring and fall with fewer large densities recorded in the winter and summer. These data may demonstrate a seasonal influx into the nearshore areas following summer breeding seasons (for the fall) and again just prior to the onset of a new breeding period in the spring. Many species found in the nearshore areas during these periods would be expected to be in transit either to or from inland areas.

Generally, many species of fish demonstrate the yearly (or seasonal) spawning migrations into the nearshore habitat. Some spawning activity may be occurring at virtually every season of the year. Many other species, on the other hand, make much smaller scale (local) movements on a seasonal or diel basis. Seasonal movement usually consists primarily of species leaving the nearshore area for the deeper waters during the winter when conditions in that habitat are the poorest. Dogfish, ratfish, and some cod fishes and rockfish move from deeper, offshore waters into the nearshore waters at night for foraging purposes.

Juvenile salmon usually move through the nearshore habitats as well as offshore waters as they migrate to sea in the winter and spring. Adults of these species move into the study area through the offshore waters in the summer and fall.

Adult herring usually move from offshore waters into the nearshore areas for spawning purposes from December through June; the timing is dependent upon the location of the spawning grounds. Juvenile herring remain associated with these nearshore waters until the late fall when they move into deeper water.

Surf smelt swim into nearshore waters for spawning. Spawning on intertidal beaches can occur during any month but is usually site specific. Other than the fact that movements into nearshore waters for spawning occur, as with longfin smelt which spawn in streams, the extent or duration of surf smelt movements is unknown.

Cod fishes usually move into nearshore waters during spawning migrations in the winter months and become dispersed offshore during the rest of the year. Juvenile cod, however, often remain in the nearshore area until they are one year old before moving out into deeper waters.

IV. 3. B. e. Variability. The nearshore water was perhaps the most consistently monitored area (for fish, birds, and mammals) during the MESA program. Thus, one expects that any natural variability would have been adequately documented. However, the difficulties of sampling far-ranging study sites using a variety of methods has generated some uncertainty as to the adequacy of the data. Some variability in biologic data observed in the nearshore zones may be entirely related to methodology.

Harbor seals were the dominant mammals of nearshore waters, though many other species were also observed. Censusing methods concentrated on haul-out areas, thus data for nearshore and offshore waters are minimal. Difficulties in observing mammals which haul out are magnified when the animals are in the water. Glare, waves, wide dispersal and submergence of the animals, disturbance by aircraft, and formation of pods are factors directly affecting estimates of population sizes.

Generally, recent collection of data on marine mammals in the study area, while providing a basic inventory, are not of the quality to detect subtle variations.

While there was considerable variation in bird species composition in the intertidal/subtidal habitat types, there was remarkable similarity in the species foraging in nearshore waters overlying the various substrate types. The seasonal lists of the most frequently observed species (Appendix Tables III-I through III-P) were comprised of a relatively few species, each occurring in a number of nearshore habitats.

The sources of variability in bird data included site-specific short-term phenomena, such as herring spawning and tidal turbulence, observer vision, glare, waves, and other weather-related factors, disturbance caused by the censusing vehicle (boat or plane), taxonomic ability, submergence of diving birds, and diurnal movement patterns of some species. "Normal" seasonal variations related to migrations, breeding, nesting, etc. add further sources of variability. The two-year study period provided insufficient data for documenting annual variations in bird populations using nearshore waters. Substantial variations are probable. These relate to the success of the previous breeding season and to variations in productivity of the marine systems.

A major source of sampling error for nearshore fishes was likely related to gear selectivity. Each gear type used would tend to selectively sample any given area and direct comparison of catches from different gear types could be misleading. However, in most cases data from similar gear types were comparable. Other uncontrollable variation was a result of bottom topography, weather conditions, sea conditions, etc.

A decrease in total number of fish species collected was observed in beach seine catches as the MESA study progressed, due largely to an unusual appearance of rare species in the first year's catch. The presence or absence of these locally rare species (rock greenling, Pacific sandfish, plainfin midshipman, and kelp perch) was not considered significant.

The rank order of the most abundant species caught in tow net samples was generally consistent from year to year (Table 7) and suggests that for some species habitat occupation is fairly constant. Differences between years may be a result of the random occurrence of unusually large numbers of individuals of a species. Variation in age class abundance could also affect the rankings. For example, few speckled sanddabs were collected early in the MESA study; abundance of this species increased markedly during later years.

Pacific herring and other schooling fish often dominated the tow net catches. Pacific herring are most abundant in the spring and summer as larvae and juveniles. Few herring were caught in the fall and winter as this species moved into the offshore waters. A difficulty in assessing the habitat preference of herring was encountered and was attributed to the schooling nature and, thus, patchy distribution of this species. Most smelt were collected in the western Strait of Juan de Fuca in the summer and fall months corresponding to spawning activities in the nearshore areas. Between-year and between-season variability in tow net catches (as shown in the Strait data in Figures 27, 28, 29) often resulted from influxes of schooling fish, such as the clupeids and osmerids. While species richness remained fairly constant, abundance and biomass occasionally varied widely. For example, the summer 1977 sample at Morse Creek was highly unusual for a site that normally had low-density, low-biomass catches.

Species richness of nearshore fishes was greatest during summer and fall and diminished in the winter and spring. This trend may generally reflect an influx of larvae and juveniles into nearshore waters during these seasons. Densities of fishes caught followed a similar pattern.

IV. C. Offshore Waters

IV. C. 1. Habitat definitions. Offshore areas with water depths of 20 m (60') or greater comprised a set of habitats which differed in many respects from the shallower areas. These areas were characterized as parts of the MESA plankton, bird, and mammal studies.

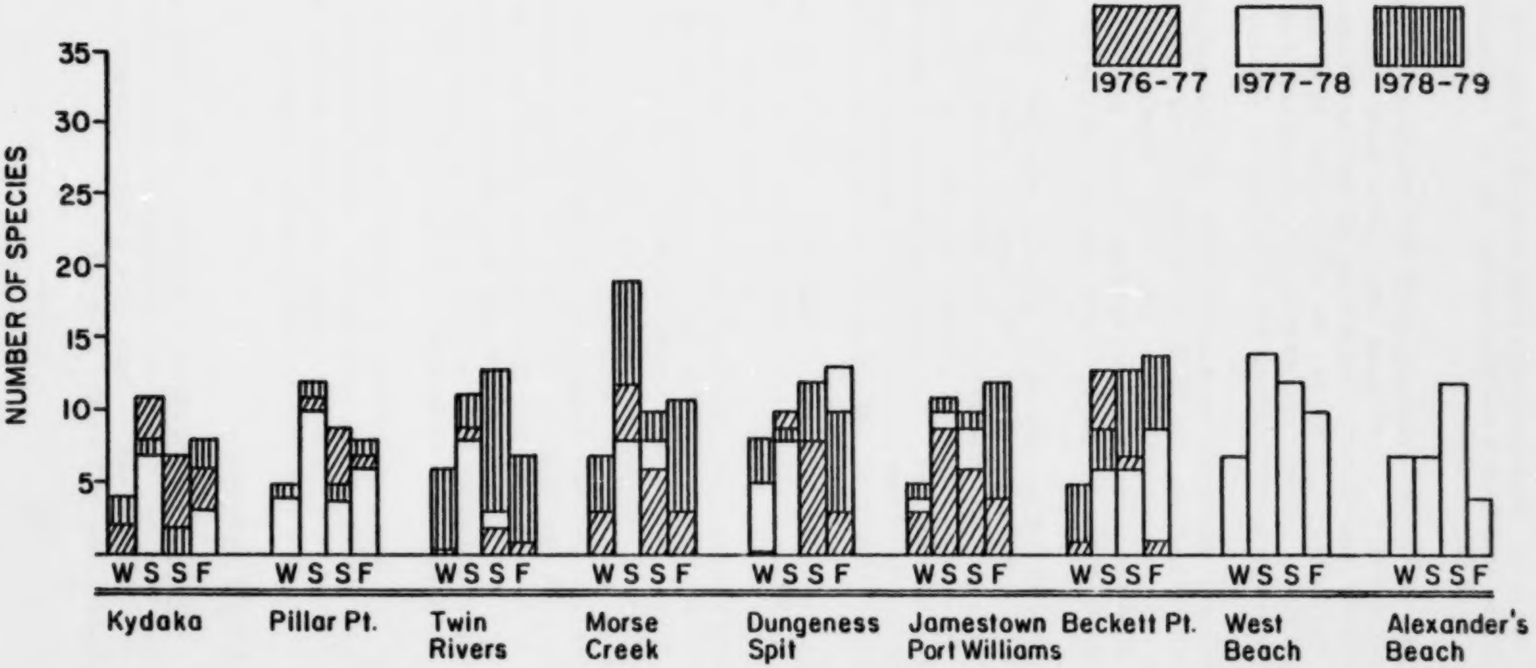

Figure 27. Number of species of fish caught per season(winter/spring/summer/fall) at nine nearshore sites along the Strait of Juan de Fuca, 1976-1979 (from Miller et al., 1980).

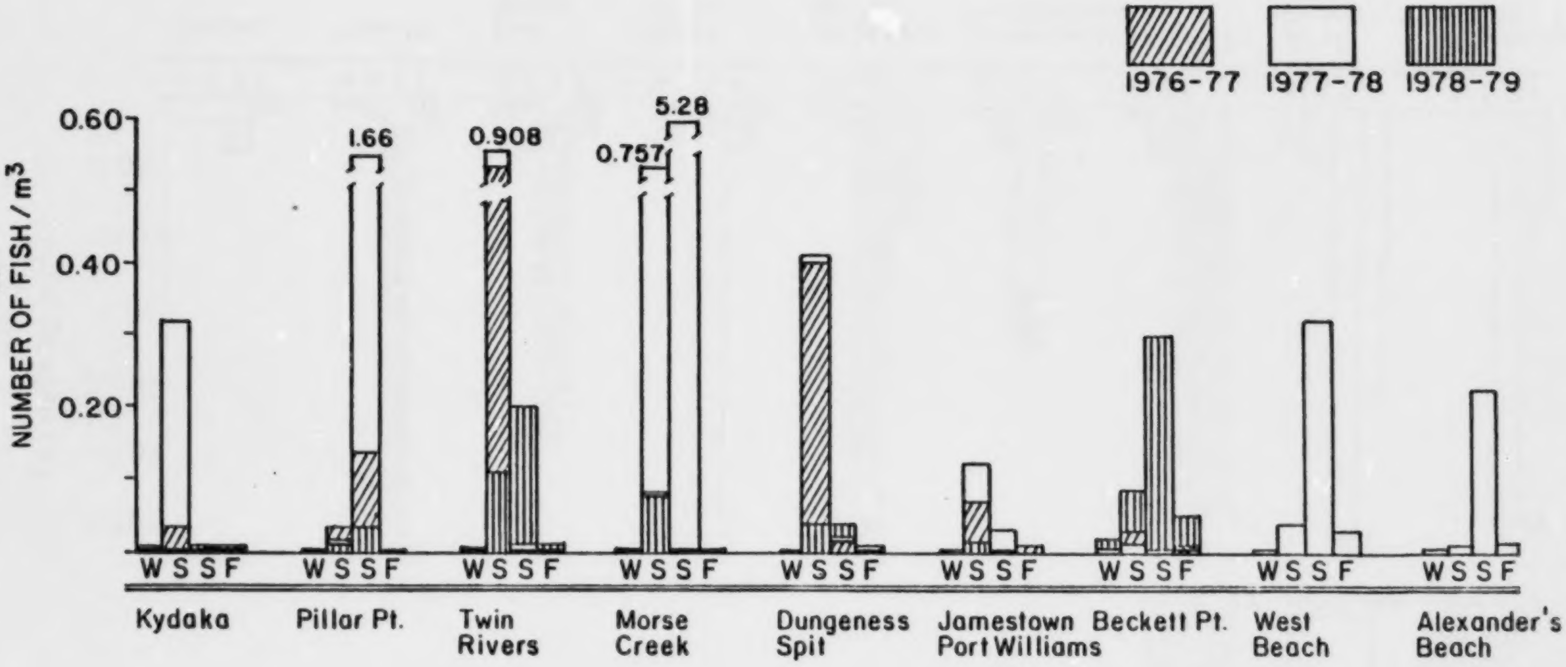

Figure 28. Density(no./m^3) of fish caught per season(winter/spring/summer/fall) at nine nearshore sites along the Strait of Juan de Fuca, 1976-1979(from Miller et al., 1980).

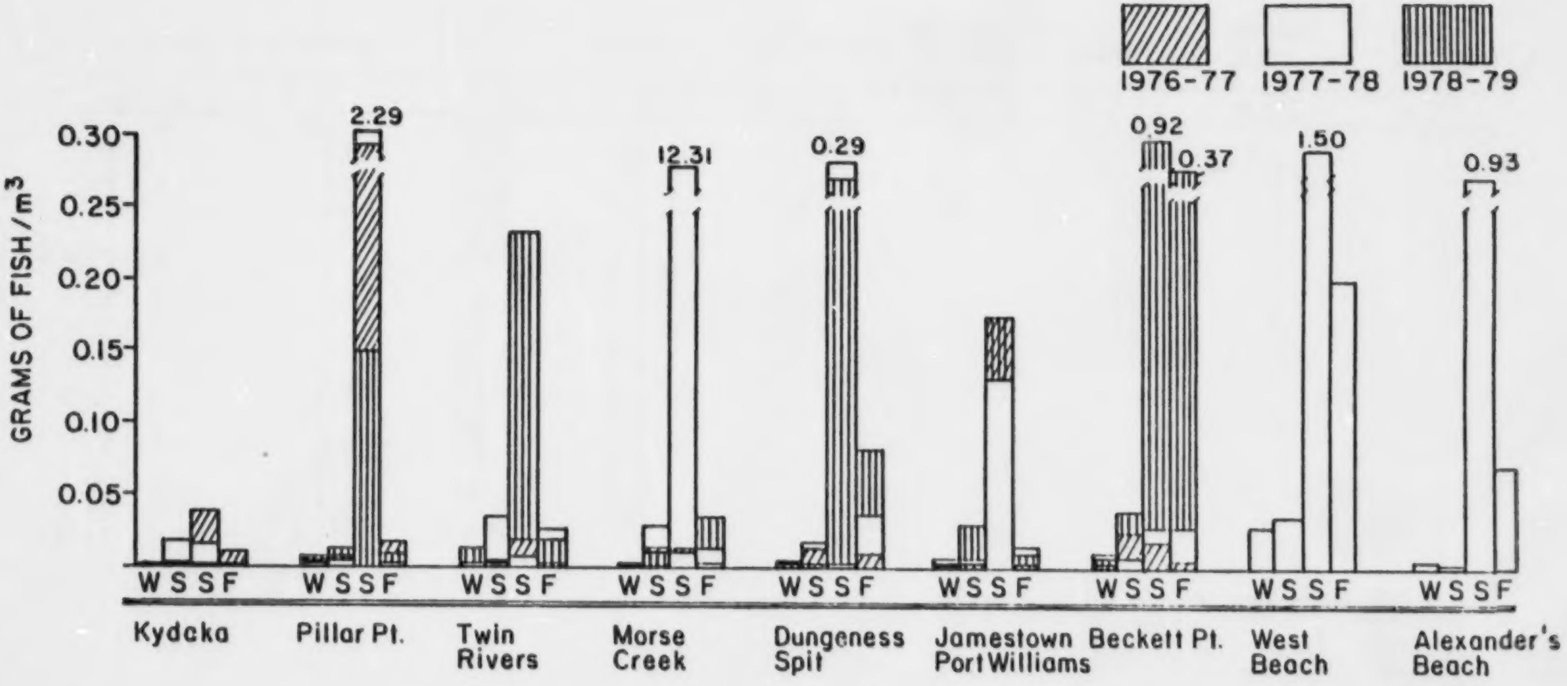

Figure 29. Biomass(grams/m^3) of fish caught per season(winter/spring/summer/fall) at nine nearshore sites along the Strait of Juan de Fuca, 1976-1979(from Miller et al., 1980).

These deep water areas have been classified here as three types: the deeper portions of several embayments in the study area; passages; and the extensive open water areas of large bodies like the Strait of Juan de Fuca. Note that these habitat types are not "pelagic" in the oceanic sense, though processes may be similar in many respects.

IV. C. 1. a. Bays. Several embayments in the study area have deep offshore areas that showed pronounced species differences from immediately adjacent nearshore waters. Discovery Bay and Bellingham Bay had sizable offshore components. Padilla Bay was largely composed of shallow eelgrass beds; but its outer portion was deep and, like Discovery and Bellingham Bays, the marine bird species composition changed abruptly at about the 20 m depth contour.

IV. C. 1. b. Narrow passages. Deep narrow passages between land masses in the study area featured strong tidal currents and turbulence along tidal fronts. Areas such as Speiden and San Juan Cnannels were included in this habitat type. Areas of extremely strong tidal exchange like southern San Juan Channel near Cattle Point and Active Pass in Canadian waters were also included. Tidal fronts were more common in passages than in deep bays or open waters.

IV. C. 1. c. Open waters and broad passages. A large proportion of the offshore waters were within the Strait of Juan de Fuca and southern Strait of Georgia. These contained very deep, open waters; and while tidal fronts were noticeable, they often had lower current velocity and less tidal turbulence than narrow passages. We have included Haro Strait, Rosario Strait, Admiralty Inlet, and Bellingham and Presidents Channels in the broad passage habitat type.

IV. C. 2. Spatial extent. About 88% of the water surface in the study area covers depths greater than 20 m (Table 5). About 4% of these offshore waters are components of large bays like Discovery Bay and the Bellingham-Samish-Padilla Bays complex and small bays within the San Juan Islands. The deep passages make up about 21%. The Strait of Juan de Fuca waters comprise about 61% of the total deep waters of the study area, and the study area portion of the southern Strait of Georgia makes up 14%.

The offshore waters include a very high proportion of the total water volume of the study area. Assuming average nearshore depth as 10 m, and average offshore depth as 100 m, about 99% of the volume of the Strait of Juan de Fuca would be in the offshore waters.

IV. C. 3. Major Biological Assemblages

IV. C. 3. a. Community description. The four offshore habitats resemble each other in a number of ways; and some of the variation between habitat types probably represents conditions at arbitrarily selected points on a scale grading from narrow, turbulent passages like San Juan Channel at Cattle Point to apparently featureless waters in the middle of the Strait of Juan de Fuca.

One of the most characteristic features of the offshore community as presented here is that some of the predominant and most visible species are usually not directly associated with the bottom community. These species function primarily at the surface and in upper and middle levels of the water column. Plankton and fish along with the marine birds and mammals which, in turn, prey mostly on plankton and fish, comprise the community.

Animals usually appear to have a "patchy" or "clumped" distribution, presumably reflecting concentrations of their prey items. Major proportions of marine bird populations observed in the offshore waters were in areas of fronts between water masses: tide rips, convergence and downwelling zones, etc.

Thus, the discussion below will focus on interspecific, primarily feeding, relationships and on important phenomena such as the tidal fronts. We stress, again, that few data are available for offshore mid-water organisms and even less is known of offshore bottom waters.

At least 21 species of marine mammals have been reported in the offshore waters of the study area. They primarily use these waters for feeding and migrations. The gray whale, minke whale, killer whale, harbor porpoise, and Dall porpoise were the most common cetaceans. The harbor seal, though primarily a nearshore inhabitant, was the most common pinniped.

Four species of fish-eating birds were most common in offshore waters: the Common Murre, Brandt's Cormorant, Western Grebe, and Arctic Loon. Although variable in their feeding habits over the spectrum of pelagic fishes available to them, these birds occurred in relatively predictable periods and concentrations as a function of breeding, roosting, and migration. The mobile, gregarious birds foraging in offshore waters functioned sometimes in pure flocks of one species, and often in multispecies assemblages. They were capable of taking advantage of feeding opportunities which existed for a very brief time when schools of fish were near the surface or during periods when prey concentrations were found in tidal fronts.

A composite of the 10 most frequently observed bird species per season within the four offshore habitats (Appendix Tables III-U through III-X) indicates 28 species utilize offshore habitats. One species (Hooded Merganser) is considered incidental in the offshore habitats. Of the remaining species, 16 can be considered obligate piscivores, three can be considered obligate planktivores (Fort-tailed Storm Petrel, Northern Phalarope, and Cassin's Auklet), two are gulls which specialize on large plankton and small fish (Bonaparte's and Mew Gulls), one is a kleptoparasite while in the study area (Parasitic Jaeger), and the remaining species are omnivores (large gulls).

The offshore bird population is composed of large numbers of a relatively few species when compared to nearshore habitats. As an example, Table 8 shows characteristic winter bird species composition and percent of total estimated population for winter in offshore waters of some regions.

Table 8. Percentage of estimated total winter populations of major marine birds by species or species groups for selected offshore regions and total densities per region, 1978-1979.

	Western Strait of [1]Juan de Fuca	Eastern Strait of Juan de Fuca	Admiralty Inlet	Western Strait of Georgia	Eastern Strait of Georgia	Southern Rosario Strait	Active Pass	Offshore Bellingham Bay
Diving birds								
Loons[2]	< 1	< 1	1	2	6	4	21	3
Grebes[3]	< 1	1	7	2	6	< 1	< 1	62
Cormorants	< 1	4	1	1	2	10	40	2
Common Murre	68	28	26	36	39	59	6	9
Other alcids	1	3	7	5	7	2	< 1	2
Other species								
Ducks	< 1	9	4	3	19[4]	1	3	10
Gulls	30	56	53	49	23	24	29	11
Total estimated birds	37,000	36,000	3,000	1,300	22,000	9,500	4,000	32,000
Birds/km^2	19.6	22.1	50.8	3.5	76.6	84.8	385.5	258.7

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[1] Gulls may be overstated: some data from ferry - no allowance for ship following here.
[2] Almost all Arctic Loons.
[3] Almost all Western Grebes.
[4] Mostly Oldsquaws.

Source: unpublished MESA data.

Species and groups of species of birds and mammals differ in their use of the offshore areas, relating to needs to come ashore diurnally or seasonally during their presence in the study area. Several species have no direct ties with nearshore habitats while they are present within the study area. The cetaceans do not come ashore at all under normal circumstances. The murres, with a fall-winter population likely in the hundreds of thousands, form one of the major components of the offshore system and are almost exclusively dependent upon it (Table 9).

Table 9. Percentage of selected major wintering bird species occurring in offshore waters in the study area.

	Number estimated in study area	Percent in offshore waters
Arctic Loon	4,800	82
Western Grebe	72,000	77
Brandt's Cormorant*	3,700	58
Common Murre	81,000	96

*Some censused at roosts onshore; numbers using offshore waters understated. Source: Unpublished MESA data.

Other species use the offshore waters to a large extent for foraging but spend a proportion of their lives ashore. These include Brandt's Cormorants, which roost ashore. The Rhinoceros Auklet spends all its nonnesting season on the water, otherwise coming ashore nightly during its spring-summer nesting season. For these highly specialized diving animals, the foraging opportunities of the offshore areas are essential. In the case of a species like the Rhinoceros Auklet, breeding within the study area and foraging offshore, reproductive success and maintenance of adult populations may depend on localized food resources of the offshore area.

For fishes there has been little effort to identify the offshore water assemblages in the Strait of Juan de Fuca or northern Puget Sound. Nevertheless, it is reasonable to separate the offshore fishes into surface organisms (upper few meters of the water column), mid-water (from a few meters below the surface to a few meters above the bottom), and demersal (on the bottom and a few meters above it).

The offshore surface waters were particularly notable during the winter and spring months for large quantities of pelagic fish eggs and larvae. The most common eggs were those of flatfish species (which all have pelagic eggs except rock sole); but there were also eggs of the cod fishes, pollock, hake, and probably tomcod (but not Pacific cod which have demersal eggs). The variety of larvae found in the offshore surface water was great (Chester et al., 1977), including smelts, cod fishes, sculpin, and flatfishes. They were dominated by the greenlings (including the lingcod), mostly one or more species of Hexagrammos (white-spotted-, kelp-, or rock-greenlings). There were also some juvenile and adult fishes seen in offshore surface waters, but quantitative data are lacking. Juvenile and adult herring may congregate right at the surface (herring balls) at most any time of the year or time of day, although the youngest juveniles are known to school at the surface at dusk (Hart, 1973). Many marine birds were attracted to these herring balls. At times juvenile salmon were seen migrating at the surface across open water (such as the Strait of Georgia), and even adult salmon (and other fishes) were occasionally found right at the surface. The nature and predictability of these surface aggregations has not been determined.

This apparent unpredictability fits into the well-known foraging pattern of gulls over the water surface. Feeding assemblages of birds are apparently unpredictable in time and space. Enough study has not been done to determine if the gulls are the nuclear species, the species that starts feeding assemblages. But the foraging pattern of gulls is such that it allows for the finding of unpredictable food sources. Once an individual finds a food source, its behavior communicates to other gulls and other bird species the presence of food. Fishermen have learned to read these feeding activities as well. There is some thought that the Rhinoceros Auklet may drive prey items, schooling fish, to the surface and make them available to a variety of surface foragers.

Offshore mid-water also apparently supports sizable aggregations of fish, but standardized survey data are again generally lacking. It is not likely that many pelagic fish eggs occur in offshore mid-water (although it should be noted that many pelagic fish eggs eventually sink from the surface waters). Chester et al. (1977) indicated from the oblique bongo net tows they made in the upper 50 m offshore stations, that a fairly diverse assemblage of larvae was present including the more abundant Pacific herring, in addition to smelts, Pacific sand lance, cod fishes, sculpins, pricklebacks (blennies), rockfish, English sole, rock sole, and other flatfish. There has been no systematic offshore mid-water survey of juvenile and adult fishes in the Strait of Juan de Fuca and northern Puget Sound, but clearly such waters are the primary or secondary habitat of most adult and many juvenile pelagic fish species. Many species are fished commercially and recreationally in the offshore mid-water, such as spiny dogfish, Pacific herring, salmon (all five species), cut-throat trout, steelhead trout, surf smelt, Pacific cod, hake, tomcod, pollock, Pacific sand lance, and several species of pelagic rockfish. Some of these fishes occur in the offshore mid-water during one season (e.g., herring adults, chinook salmon adults) or during a particular life history stage (e.g., juvenile herring and salmon), while other species occur throughout all seasons and life history stages (e.g., tomcod and pollock). Various combinations may also occur.

The offshore bottom waters have had little or no sampling for fish eggs and larvae. Major offshore demersal spawning may occur in deep water. For example, while there is direct evidence for lingcod spawning in the subtidal depths (i.e., <20 m) and indirect evidence for Pacific cod spawning there also, many fisheries biologists believe both the lingcod and Pacific cod also have deep offshore spawning grounds where their demersal eggs are deposited.

The evidence is also beginning to mount that there are demersal fish larvae that spend all or part of their larval life on or near (perhaps even in) the bottom. Unfortunately, the supporting evidence for the previous statements about eggs and larvae in offshore bottom waters is entirely circumstantial.

Deep offshore bottom waters are important for commercial and recreational fishing in the area. Such economically valuable demersal fishes include the demersal rockfishes (several species), sablefish juveniles, whitespotted greenling, lingcod, and flatfish (several species including the Pacific halibut). Other abundant demersal species in the offshore bottom waters which are important ecologically as forage organisms, predators, scavengers, etc. include skates (two species), ratfish, midshipman, eelpouts (two or three species), snake prickleback, bay goby, sculpins (two species), and poachers (two species).

It is worth pointing out that demersal species have been found to group primarily on the basis of depth and only secondarily by geographic locality. In central and southern Puget Sound, the demersal fishes caught in trawl collections were found to form distinct groups associated with depths of less than 30 m, 30-70 m, and greater than 70 m.

The herbivorous zooplankton included copepods such as Pseudocalanus and Calanus. Plankton carnivores included ctenophores such as Beroe and Pleurobrachia; chaetognaths such as Sagitta and Eukrohnia; and crustaceans such as Parathemisto (hyperiid amphipod), Pasiphaea (shrimp), and Podon and Evadne (cladocerans). Nektonic carnivores are primarily larval and juvenile fishes, including Pacific herring, Pacific sand lance, smelts, Pacific salmon, and greenlings. Piscivorous fishes are assumed to include maturing or resident Pacific salmon, Pacific hake, and walleye pollock.

There were some apparent differences in species' habitat preferences among offshore communities occurring in the bays, passages, and open waters of the study area, particularly as far as birds are concerned.

IV. C. 3. a. (1) Bays. Marine mammals were less frequently observed in deeper waters of the large bays than in nearshore waters. Harbor seals were the most abundant mammal in this habitat.

While the four major offshore bird species occurred in all the deeper bays, the predominant fish-eating species in Bellingham Bay, one of the major deep bays in the study area, was the Western Grebe (Appendix Table III-U); the other species were relatively less abundant.

IV. C. 3. a. (2) Narrow passages. Northern and California sea lions were observed in the narrow passages of Active Pass and San Juan Channel more frequently than in many other foraging habitats. Harbor seals were also seen in this habitat, though rarely.

The composition of bird populations in narrow passages differed from that in deep bays. Brandt's Cormorants and Arctic Loons occurred in greatest densities in passages (e.g., Active Pass, Appendix Table III-V). Bonaparte's Gull also occurred in high densities in narrow passages (Active Pass), though they also occurred in a patchy distribution throughout the offshore habitats, especially in tidal fronts where plankton was concentrated. Quantities of pelagic fish eggs and larvae occurred particularly in winter and spring; and, indeed, relatively high densities of Bonaparte's Gulls were offshore at these times (Appendix Tables III-U through III-X). Fish-eating species (Arctic Loons, Brandt's Cormorants) also occurred in peak numbers at locations and habitats where concentrations of eggs and larvae presumably attract fish. These may also relate to proximity to nesting sites, roosts, and haul-out areas (in the cases of birds and pinnipeds), or variations in oceanographic features like salinity and turbidity.

IV. C. 3. a. (3) Broad passages. Unlike birds, pinnipeds and cetaceans do not appear to be as obviously keyed on "fronts." However, killer whales travel in pods, occasionally totalling among all pods over 75 animals in the study area, and foraging within concentrations of prey (e.g., salmonids) would seem essential to even small groups. Minke whales were most often observed in broad passages or along steep shorelines with tidal convergence action where plankton and small fish prey were concentrated. While cetaceans were infrequently encountered, seabirds were occasionally observed following large marine mammals as they do in other areas.

As in narrow passages, major feeding functions of birds in broad passages resulted from concentrations of prey species in tidal fronts and eddies. This phenomenon is transitory but it is consistent and birds may, as a result, become concentrated. Prey would seem less likely to be in schools, but rather simply concentrated by currents, and cooperation between individual predators would seem less advantageous here. Gulls serve less as catalysts, and diving birds often forage independently. Both surface-feeding and underwater-feeding species usually fly up-current, and feed while drifting down-current to a presumed point where feeding becomes less efficient then they repeat the procedure.

This activity was patchy, with observed densities of animals varying greatly during censuses over the offshore waters of broad passages. As an example, density of all species in most of southern Rosario Strait was 19/km^2 in the fall, while the densities of birds on a census transect from Shannon Point to Bird Rocks were as high as 907 and 2171/km^2. The predator species involved were generally highly mobile and gregarious.

Relative abundance of bird species shifted from the patterns of bays and narrow passages in this habitat. The Common Murre was the dominant species among the fish-eating species during the fall and winter seasons, while Rhinoceros Auklets were present in summer (Appendix Table III-W).

IV. C. 3. a. (4) Open waters. Cetaceans were most frequently observed in the open waters of the study area, particularly the Strait of Juan de Fuca. Minke whales and Dall porpoise were found mostly in open waters. Killer whales and harbor porpoise were also found there, but were occasionally found in nearshore waters also.

The avian community composition of open waters resembled that of broad passages. Common Murres dominated the fish-eating species for the fall and winter period, while Rhinoceros Auklets were the abundant species in summer (Appendix Table III-X).

During aerial censuses, herring balls were observed in open waters of the Strait of Juan de Fuca being preyed upon from the surface by gulls and Rhinoceros Auklets feeding from below the surface. Gulls often find a school while foraging from the air; and, since these birds are highly visible, their feeding behavior attracts other gulls and divers, which in our study area will often be Arctic Loons, Brandt's Cormorants, Common Murres, and Rhinoceros Auklets. Additionally, jaegers steal food from diving birds and gulls. The complementary attacks on prey from the surface by gulls and from below by divers may maximize exploitation of the opportunity by tending to keep schools of prey species "rounded up." However, these feeding activities are temporary and birds attracted from long distances may arrive after prey is dispersed.

Another type of feeding is likely very important but poorly understood for the study area. This activity is related to availability of zooplankton which ascends to surface waters during hours of darkness. Many seabirds feed at night. Zooplankton availability may explain the movements of Common Murres from the Strait of Juan de Fuca into Rosario Strait in the daytime; the murres may forage on plankton and plankton-associated fish at night in the Strait, and on prey in tidal fronts in Rosario Strait during the day.

In addition, phalaropes, which are essentially fall migrants, are known to feed directly on concentrations of planktonic organisms on the surface. From mid-July to September, Northern Phalaropes were seen in drift or rip lines in open waters and passages. This activity increases with proximity to the ocean.

IV. C. 3. b. Trophic organization. The structure of the offshore food web (Figure 30) resembles the classic autotrophically-based pelagic community characterized by a phytoplankton-herbivorous zooplankton-carnivorous zooplankton-planktivorous fishes energy flow (Hardy, 1924); although it is in all probability a more complex and interlinked system (Cushing, 1970; Petipa et al., 1970).

The major forms of phytoplankton included diatoms, dinoflagellates, coccolithophorids, and various microflagellates. Microflagellates were dominant in the Strait during late fall and winter. Diatoms were dominant during spring and early summer, and occasionally during a fall bloom. Dinoflagellates reached their maximum abundance during late summer and early fall. Variability in community composition was very high spatially and between replicates.

The grouping of producer and consumer organisms into feeding categories has masked the considerable temporal and spatial variation in the taxonomic and size composition of the organisms within these groups. The herbivorous zooplankton, for instance, included both the relatively small (1-2 mm long) calanoid copepod *Pseudocalanus minutus*, which was found in surface waters at high densities, and large (2-4 mm long) *Calanus* spp. (principally *C. plumchrus*, and a complex of *C. pacificus*/*C. marshallae*) which resided

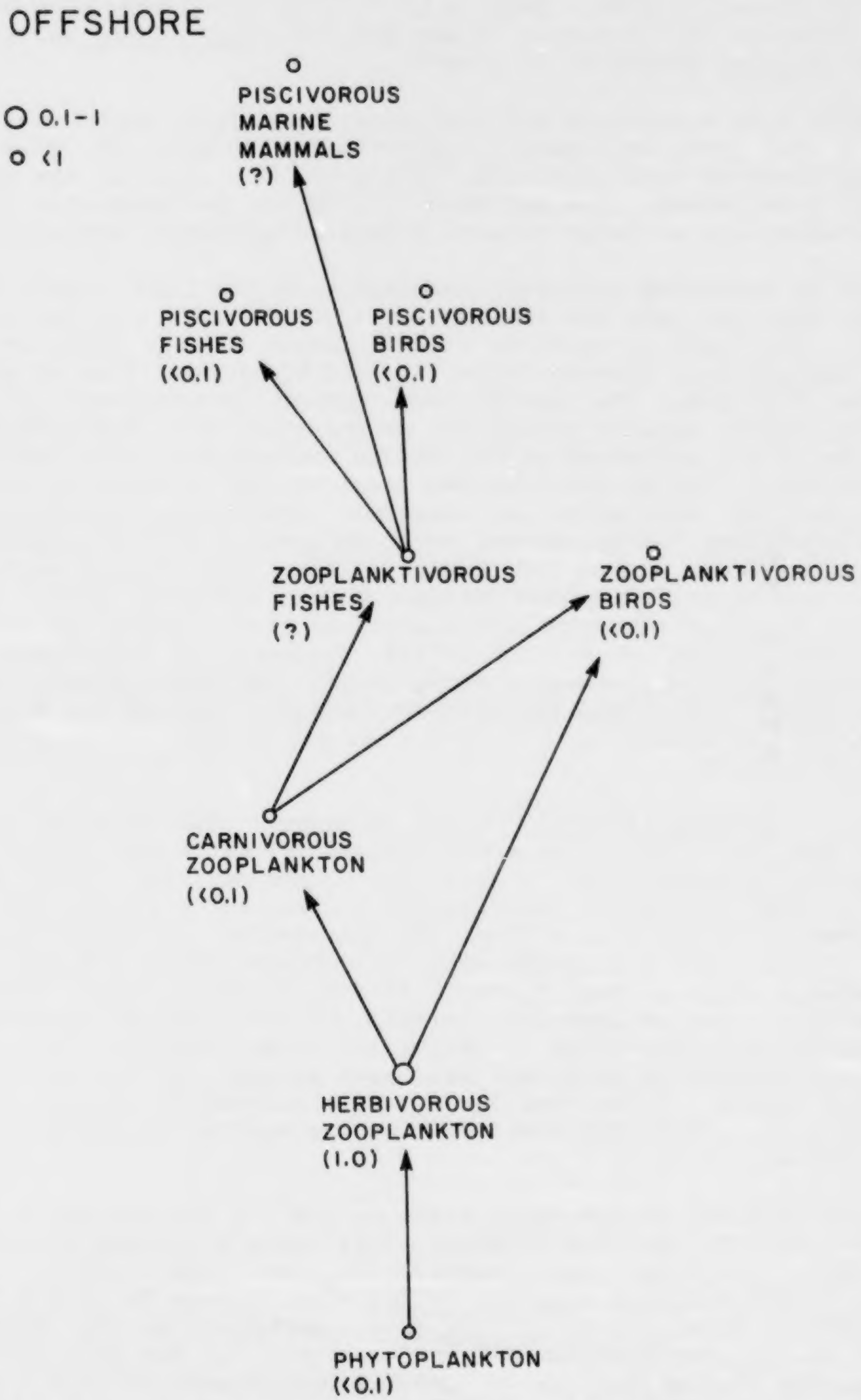
OFFSHORE
0.1-1
<1
PISCIVOROUS MARINE MAMMALS (?)
PISCIVOROUS FISHES (<0.1)
PISCIVOROUS BIRDS (<0.1)
ZOOPLANKTIVOROUS FISHES (?)
ZOOPLANKTIVOROUS BIRDS (<0.1)
CARNIVOROUS ZOOPLANKTON (<0.1)
HERBIVOROUS ZOOPLANKTON (1.0)
PHYTOPLANKTON (<0.1)

Figure 30. Characterization of offshore habitat food web. Average biomass of major taxa represented in parentheses(grams/m^2 or grams/m^3).

principally in deep water as adults, though migrating into surface waters at night. Not only are the requisite food (phytoplankton) particle sizes different for these calanoids, their relative production rate in terms of generation times are also divergent (1 per year for *Pseudocalanus* vs. 6 to 9 per year for *Calanus*) (Mackas et al., 1980).

The carnivorous zooplankton and zooplanktivorous fishes varied even more dramatically over time and space. Considering the kinds of sizes and morphological features associated with feeding by these animals, the single trophic link shown between them and their prey is not representative of the complex, variable flow of energy between primary and secondary carnivores.

Despite the tremendous potential productivity of the lower trophic level organisms in this food web, the standing stock of consumers does not appear to be high. The rapid turnover in organic matter through predation and population regeneration, however, belie the actually dynamic flow of energy through this food web. The spatial and temporal distributions of prey resources for various consumer groups are, on the other hand, highly variable and patchy due to the influences of the complex oceanographic characteristics of the study area. Strong advection and tidal mixing, wind-driven (Ekman) upwelling, and the influences of estuarine circulation contribute to large-scale patchiness in the standing stock and productivity of zooplankton (Mackas et al., 1980 ; Bowman and Esaias, 1978). These frontal processes dominate the habitat only in narrow passages such as Admiralty Inlet. Thus, secondary and tertiary consumers are limited in their ability to utilize these prey resources by the predictability, frequency of occurrence, and spatial coverage of these optimal foraging zones. So, while production and the rate of energy flow through the offshore (pelagic) food web may be high, it is typically concentrated in localized zones and is not representative of the habitat as a whole.

IV. C. 3. c. *Density, biomass, species richness*. The research design utilized to describe local marine mammal concentrations focused on the more easily observed pinnipeds which haul out throughout the study area. Consequently, there is little quantitative information available for the offshore areas. Essentially, all of the 21 species of marine mammals documented in the study area could occur in offshore areas, although some species (notably river otters) probably rarely, if ever, leave nearshore waters. Cetaceans were an important component of this area and appeared to be most abundant with the influx of spring and summer migrants. Sea lions forage in this habitat as well, and were most abundant in the study area during winter months. While some harbor seals undoubtedly forage in the offshore areas, the extent that these habitats are used by the population as a whole is unknown.

Offshore habitats are generally characterized by low numbers of bird species, low density, and low biomass. This pattern becomes especially apparent when comparing the measurements for open waters with intertidal/subtidal habitats (Appendix Tables III-A through III-H and III-U through III-X). This effect is, in part, explained by the lack of appropriate habitat for foraging for many species. In the deep offshore habitats, diving species are unable to reach the bottom to feed. Thus, species that are present must be able to feed on the surface or in the near-surface waters, or be able to dive into the mid-water column to feed or feed elsewhere. These restrictions immediately eliminate many species that are adapted to feed in shallow water areas or onshore. Additionally, many species are not capable of sustained presences in offshore habitats. This is due to a poor swimming capability, their inability to float on the water for long periods of time, or their inability to stay airborne for long periods of time. The species commonly found in offshore waters are loons, grebes, jaegers, gulls, cormorants, and alcids. These species are either strong fliers, or can stay on the open waters for indefinite periods of time; and all are specialized as surface feeders or divers.

The number of species on the offshore waters is generally low, but the total number of individuals is often high because the amount of offshore habitat in the study area is vast compared to other habitats. Thus, Common Murres in the late summer often start to invade the study area from the outer coast and peak in numbers in the late fall at which time the density may reach as high as 30 to 80 birds per km^2 in certain areas. When the total counts are projected, their numbers approach a quarter million birds in the study area, far outnumbering any other species count in any other habitat.

The offshore habitats showed seasonal patterns of abundance, with numbers generally at the lowest level during the summer months. At that time densities as low as eight birds per km^2 were common. Peak seasonal densities usually did not equal those seen in other habitats, especially the intertidal/subtidal habitats. The highest density level seen for offshore habitats was 229 birds per km^2 in narrow passages. The density levels for the intertidal/subtidal habitats reached several times this level.

Deep-water bays usually have the lowest numbers of species of all the offshore habitats. Bays, like all other habitats, show seasonal variations with peak numbers of species, density, and biomass during the winter months. The highest seasonal density and biomass levels of the offshore habitats were recorded in narrow passages where flocks of birds foraged. Even including populations associated with adjacent breeding colonies, the summer values for number of species, density, and biomass were the lowest recorded in the offshore habitats. The fall and winter numbers were only a fraction of the previous habitat values.

The open waters of the study area are the single largest habitat. Except for the summer, the values of bird density and biomass in this habitat were the lowest recorded in the study area. The summer values were only slightly larger than in other areas. However, though the values of density and biomass were low, the number of species observed was relatively high in comparison to the other habitats, perhaps due to the passage of birds between other nearshore or intertidal/subtidal habitats.

Many of the stations sampled by surface trawl in the Strait of Georgia by Robinson et al. (1968a and b), Barraclough and Fulton (1967 and 1968), Barraclough et al. (1968), Robinson (1969), and Barraclough (1967a and b) included offshore, broad passage habitats. Species richness of fish averaged 9-10 during these spring and summer (April-July) collections. And although there was no quantification of the area or volume sampled, the consistent sampling methodology allows comparisons of species density. Depending upon time of season and influence of the Fraser River plume, the typically prominent fishes included larval and postlarval Pacific herring and Pacific sand lance, larval walleye pollock and rockfish, juvenile Pacific salmon, and juvenile greenling (Hexagrammidae). Other species which were only infrequently captured in abundance included postlarval eulachon (Thaleichthys pacificus), larval starry flounder, ronquils (Bathymasteridae), river lampreys (Lampetra ayresii), and threespine sticklebacks (Gasterosteus aculeatus).

Offshore phytoplankton, zooplankton, and ichthyoplankton data were collected at nine sites in the Strait at several depths with a variety of methods. The data were reported in several documents (Chester et al., 1977; Chester, 1978; Chester et al., 1980).

Phytoplankton biomass, as measured as chlorophyll a, ranged from about 10 mg/m^2 to over 500 mg/m^2 in the upper 50 m of the water column. Most measurements were in the 10-75 mg/m^2 range. However, a distinct spring bloom was recorded in June of 1976 in which about 500 mg chl a/m^2 were observed. Diatoms contributed to much of the biomass, especially in the spring. Most samples had 1,000 to 10,000 diatoms per liter, some had up to 100,000 per liter, and those collected during the spring of 1976 bloom exceeded 1 million per liter in the upper 1 m of water. Over the two-year study, 93 species in 32 genera were identified. During the same period, 23 species of dinoflagellates in 11 genera were identified. They were less abundant than diatoms. Most samples had 100 to 1,000 dinoflagellates per liter, while those collected during the spring of 1976 bloom had 100,000 per liter in the upper 1 m of water. Coccolithophorids occurred sporadically, usually associated with oceanic intrusions of surface water.

Zooplankton settled volumes were used as an index of biomass. Most samples taken in oblique (50-0 m) tows with 333 μm mesh size nets captured less than 1 ml/m^3, often less than 0.5 ml/m^3 in the fall and winter. Some samples taken in the spring had up to 2 ml/m^3. Finer-mesh (211 μm) vertically towed nets often captured 1 to 2 ml/m^3 in the upper 100 m with a maximum of 16.6 ml/m^3 during the spring of 1976 bloom. More than 100 species of zooplankton were identified, 60 of which were copepods. Four species of euphausiids and four of chaetognaths were found. During the spring of 1976 bloom, 80% of the numbers of zooplankton collected were of a single copepod type (Pseudocalanus spp.).

Ichthyoplankton densities in oblique tows (333 μm) from 50 to 0 m depth ranged from less than 0.1 to 0.7 eggs/m^3 and from less than 0.1 to 0.7 larvae/m^3. Pleuston net (333 μm) samples ranged in densities from less than 1 to more than 10 eggs/m^3 and less than 1 to over 100 larvae/m^3. Ichthyoplankton were clearly most concentrated near the surface, as indicated by the pleuston net samples. They also were most concentrated in the spring and summer months (April through June). Numbers of taxa ranged from 1 in winter (November) to up to 20 in late winter (March) in oblique tows and 1 in late summer (August-September) to 13 in late winter-early spring (March-April) in pleuston nets. Biomass data were not collected.

IV. C. 3. d. Migrants. Generally, migrations can be considered as falling into two categories. The first involves local populations which typically perform small-scale or short movements from one local area to another. The second category includes large-scale movements performed by large numbers of animals (generally belonging to one species) moving through the study area to the extremes of their ranges. Often these movements can cover many thousands of miles.

Movements of marine mammals were difficult to assess with the survey methodologies used in the study. Cetaceans were generally more abundant in the spring and summer months presumably in response to increasing productivity in the study area. However, survey efforts in the fall and winter have been so low that lack of any species in an area during this period may simply imply no data. As an example, the Dall porpoise was usually seen in our surveys in low numbers during the fall and winter. However, this species was regularly observed throughout the Strait of Juan de Fuca from recent surveys conducted aboard the NOAA ship John Cobb in the fall and winter of 1979-1980.

Certainly one of the most unique movements of marine mammals in the study area is the long migration of the California gray whale from its breeding grounds in Baja California to its foraging areas in the Bering and Chukchi Seas. During the late winter-early spring, this species moves northward through Washington's coastal waters, passing through the far western Strait of Juan de Fuca between Tatoosh Island and Pachena Point. Occasionally, individuals penetrate deep into the inland waters. The majority of the gray whale population also pass through to Washington waters during their southbound migration in the late fall.

The most notable movements of pinnipeds are made by California and northern sea lions, described above as foraging in offshore and nearshore waters and hauling out on rocks. Both species were observed to enter the inland waters in the late fall, peak in abundance in the winter, and decrease through spring. By summer both species were essentially absent from the study area. Presumably, these movements are timed with the onset of breeding activities (outside of Washington) in the spring.

The effects of migrations were reflected clearly in the seasonal rise and fall of bird densities at the various census points in the study area. Typically, many species are highly migratory and can be expected in the study area only during certain times of the year. The most dramatic example of a large-scale movement through the study area was that of the Common Murre. This species was observed to enter the study area in large numbers in the early fall (August to September). By late winter-early spring, a movement to breeding areas along the outer coast south to the Farallon Islands and north to Alaska occurred.

Another example of migratory seabirds in the study area is Rhinoceros Auklet which were absent from the area in the late fall and winter, spending those seasons along the outer coast south to southern California and returning to breeding islands (primarily Protection Island) in the spring and summer. Other species that usually come up the coast included the Heermann's Gull, which entered the Strait of Juan de Fuca in the late summer.

Generally, bird movements through this area follow the pattern demonstrated by the Common Murre--abundant during the nonbreeding fall and winter and virtually absent during the breeding periods (spring and summer). Included in this scenario are Western Grebes which typically leave in the spring for breeding sites inland; Arctic Loons which arrive in the winter from northern nesting grounds; and Brandt's Cormorants entering from coastal areas. Large numbers of gulls (Bonaparte's, California, Mew and Thayer's) pass through the study area during fall migrations and spend a large portion of their time foraging in tide rips and other productive areas (often in nearshore waters). The only offshore "ducks" in this area are several thousand Oldsquaw which usually appear in late fall and remain through spring. They are often particularly abundant in the eastern Strait of Georgia and deep bays (e.g., Discovery Bay).

Smaller-scale movements of birds are less easily understood but small numbers of phalaropes, storm-petrels, Sooty Shearwaters, and Tufted Puffins migrate through the study area in the spring and fall. They often remain into summer or winter, respectively. Many of the species leave breeding areas within the study area during winter months to forage in offshore water.

The offshore waters in the study area are used extensively by fishes in their migrations. Most notable are the adult salmon migrations (all species) in the summer and fall when the salmon move through the Strait of Juan de Fuca, Hood Canal, Puget Sound, and north through and around the San Juan Islands and Georgia Strait to the Fraser River and other smaller rivers and streams. Juvenile salmon reverse the migrations to the open ocean. Although pink and chum salmon appear to use both the nearshore and offshore waters as they migrate to sea, juvenile sockeye, chinook, and coho appear to primarily utilize the offshore waters. Steelhead trout also utilize the offshore waters for migration purposes in much the same manner as salmon do.

Adult herring make large offshore spawning migrations from the ocean to their major spawning grounds along the shoreline from Sandy Point to Birch Bay in the Georgia Strait. They also move to other spawning areas along the Strait of Juan de Fuca, among the San Juan Islands, in Hood Canal, and in the Puget Sound central basin. Spawning and, presumably, most of the migrations occur from about December to June with generally the earlier spawning in southern areas and later spawning in the more northern areas. Although juvenile herring are initially clearly associated with nearshore waters, they usually move to deeper offshore waters in the winter as they continue their migration to the ocean.

Surf smelt migrations are not well-understood. Spawning occurs in most months of the year on saltwater beaches, although specific time varies among sites. The later larvae, juveniles, and adults occur in the offshore waters; but it is not known whether extensive migrations are made or just local movements in the general vicinity of spawning grounds. Longfin smelt spawn in the fall in freshwater streams, and adults are often caught near the bottom in offshore waters. As with surf smelt, it is not clear what the pattern or extent of migrations or movements are between the nearshore and offshore waters other than the fact that there is movement.

Among the cod fishes, Pacific cod spawning migrations are well-documented. Cod migrate through the Strait of Juan de Fuca to spawn in the nearshore waters of Protection Island, Port Townsend Bay, and elsewhere during the winter and then disperse into the offshore waters of the Strait to feed for the remainder of the year. Juvenile Pacific cod appear to move out of nearshore areas to the offshore water of the Strait of Juan de Fuca by the time they are one year old.

Lingcod make spawning migrations in the winter and spring from offshore bottom waters to nearshore waters for the purpose of depositing eggs in a nest on rocky substrates. While female lingcod then return to deeper waters, male lingcod precede the female from offshore waters to nearshore waters and remain to guard the nests for several weeks following spawning. However, it has not been established what percentage of lingcod spawning is also done on offshore bottom reefs rather than on nearshore reefs. Thus, it is unknown what percentage of females or males remain in the offshore bottom waters.

Finally, there is a true migration different than the usual once-a-year seasonal spawning migrations. This migration is part of the life cycle of the sablefish and yellowtail rockfish, and perhaps other species. Based on the indirect evidence that the larvae and early juveniles of these species have not been caught in the extensive nearshore sampling, this migration probably occurs primarily in the offshore waters. Only juvenile (i.e., sexually immature) specimens of sablefish and yellowtail rockfish have been caught in Puget Sound, Hood Canal, the San Juan Islands, and the eastern half of the Strait of Juan de Fuca. Several age groups of both species have been caught. When they become adults (sexually mature), they migrate out to the open ocean where spawning occurs--this pattern has been demonstrated to a very limited degree by tagging, but the evidence is primarily circumstantial, based on research samples and commercial and sportfishing catches. The adults do not migrate back to inland waters after spawning, but remain in or near the open ocean. However, the larvae and/or juveniles migrate back into Puget Sound and the San Juan Islands area. As stated earlier, the term "migration" is used in this report to include both passive (larval drift) and active transport (swimming).

Many species show local, small-scale movements on a seasonal and/or day-night basis that are correlated with physical factors such as temperature, protection from predators, and amount of light, or biological factors such as feeding activity. Seasonal movement between the offshore and nearshore waters seems to be primarily a matter of nearshore species moving into offshore waters in the winter when the nearshore hydrographic conditions and, perhaps, food supply are poor, rather than seasonal movement by offshore species into the nearshore. An exception is migrations involving spawning; it appears that offshore species spawning in the nearshore areas stop feeding enroute to the spawning area. Examples of nearshore species moving into the offshore waters in the winter include black rockfish, juvenile yellowtail rockfish, surfperches, herring, and smelt. It is also known that day-night movements of fish take place, consisting primarily of nocturnal feeding forays of offshore fishes into the nearshore waters. Dogfish, ratfish, cod fishes, and some rockfish are examples of fishes exhibiting this behavior.

IV. C. 3. e. Variability. The limited data base presently available for cetaceans in the study area precludes any assessment of variability at this time. Since offshore whales usually occur in small numbers or in pods, their occurrence at any location at any time is totally unpredictable. However, the general migratory patterns of killer whales in and adjacent to the study area are fairly well known. Thus, it is likely to find these animals in the southern Strait of Georgia in the summer in search of Fraser River salmon. For both California and northern sea lions, arrival and departure dates were comparable for both years of the study. However, total numbers of animals varied from year to year for California sea lions.

For seabirds, offshore species richness varies by season with a greater number of species occurring in descending order in the fall, spring, winter, and summer. Total abundance of all species does not follow this trend; largest numbers occur in the fall and decline through the winter and spring, and reach a minimum in summer.

Absolute arrival and departure dates for some migratory seabirds may vary somewhat from one year to the next. For example, two species that are a large component of the offshore winter population--Western Grebes and Common Murres--arrived at different times over the two-year study period, and were about two weeks later in 1979 than in 1978.

Considerable variability in species composition among offshore regions was observed. The reasons for these differences (see section IV.C.3.a) are not understood but may relate to prey availability. The standard deviations calculated for offshore abundance data (Appendix Tables III-U through III-X) demonstrate that variability among sites representing a single habitat type is often very high.

Diurnal variability differs with the season. In nonbreeding seasons, seabird numbers in offshore waters are similar during all hours except that cormorants and gulls which feed in offshore waters come ashore at night to roost. During the spring and summer breeding months, apparently few seabirds remain offshore at night. Although some may continue to feed at night, most nesting cormorants, gulls, and Rhinoceros Auklets are usually onshore.

The MESA data demonstrate considerable unexplained variability in bird usage of offshore regions in the course of the two-year study. The projected abundance estimates for many areas differed in 1978 and 1979. It is possible that much of this variability may relate to yearly differences in the location of prey species or to sampling frequency or to the location of the boundaries of artificial census subregions.

V. IDENTIFICATION OF AREAS OF BIOLOGICAL IMPORTANCE

V. A. The Need for Identifying Areas of Importance

In this chapter the focus is on those particular characteristics that for one reason or another make a particular habitat important. Factors that we have selected which can be used to evaluate the importance of a habitat include: algal/eelgrass biomass; benthic faunal biomass; occurrence of detritus; the use of a habitat for foraging by fish, birds, or mammals; the use for reproduction, rearing, migration, or resting; and the human uses of harvesting (both commercial and recreational), recreation, etc.

Sites representing various habitats for which data on one or another importance factors are available will be discussed. It might be expected that other unstudied sites will also have these important functions and uses.

For resource managers concerned with the impact of human use on the marine environment, these importance factors identify those characteristics of a habitat that should be carefully evaluated. These importance factors and their criteria can be of value in estimating the relative biological importance of unstudied areas of known physical characteristics. Although one should not conclude that a particular importance factor will always be found or applicable at an unstudied site, past experience indicates that, in the study area, there is a strong possibility it will be found when studied.

V. B. Importance Factors and Descriptions of Examples

V. B. 1. Rationale for approach. The synthesis team that prepared this report was unable to determine what specific sites or subregions in the study area were, overall, highly important, though each had identified sites that appeared to be important to the respective taxonomic group(s) they studied. The data base was incomplete geographically and topically. Research emphasis was not applied uniformly and continuously to all areas, thus all parts of the study area could not be treated equally.

The approach taken in this chapter was selected to allow the readers a framework for making their own decisions regarding the relative biological importance of specific sites. This approach assumes the reader is physically and technically able to determine the physical characteristics (e.g., exposure and habitat type) of the sites or subregions of interest. Following that step, the reader can refer to Table 10 to determine which factors are to be considered in evaluating the site of interest. The accompanying text provides a brief description of each importance factor and how it applies to each of the habitat types of the study area.

Table 10. Importance factor/habitat matrix and sites exemplifying each habitat type.

	Habitat Type	Importance Factors: Nonharvesting	Harvesting	Roosting	Migration	Rearing	Reproduction	Foraging	Detritus	Benthic Faunal Biomass	Plant Biomass	Example(s)
INTERTIDAL-SUBTIDAL	1. Mixed coarse	x		x	x	x	x	x				Dungeness Spit Ebey's Landing
	2. Sand	x			x	x	x					West Beach Eagle Cove
	3. Mud-gravel		x		x	x		x	x	x	x	Beckett Point
	4. Mud-sand	x	x	x	x	x		x	x		x	Birch Bay Jamestown
	5. Mud		x	x	x	x		x	x	x	x	Padilla Bay Westcott Bay
	6. Exposed rock	x	x	x	x		x	x		x	x	Tongue Point
	7. Protected rock	x	x	x	x	x	x	x		x	x	Point George Fidalgo Head
	8. Cobble	x	x	x	x	x	x	x		x	x	Cherry Point Morse Creek
NEARSHORE	9. Mixed coarse			x	x							Dungeness Spit
	10. Sand			x				x				West Beach
	11. Mud-gravel			x		x		x				Beckett Point
	12. Mud-sand			x		x		x				Jamestown
	13. Mud			x		x		x				Padilla Bay
	14. Exposed rock	x	x					x				Pillar Point
	15. Protected rock	x	x					x				Point George
	16. Cobble	x	x	x		x		x				Cherry Point
OFFSHORE	17. Broad passages		x		x	x		x				Admiralty Inlet
	18. Narrow passages		x		x			x			x	Active Pass. Speiden Channel
	19. Bays	x	x	x		x		x			x	Bellingham Bay
	20. Open water		x	x	x	x		x				Western Strait

V. B. 2. Description of importance factors and criteria.

V. B. 2. a. Recreational and educational use (nonharvesting). One important use of intertidal and nearshore habitats is for nonharvesting recreational uses, such as use of habitats for photography, beachcombing, education, tide pool observing, shell collecting, scuba diving, and bird-watching. The bays are important for photography and boating (Table 10). This list is not exhaustive, but, instead, is illustrative of the kinds of uses humans make of these habitats.

Some of these human uses are compatible with the ecological function of the habitats. Some have a detrimental impact, while others depend on biological components. Beachcombing, sunbathing, and swimming are not dependent upon and have little impact on biological resources. Educational field trips, tide pooling, and scuba diving are dependent upon the biological resources; and, as long as collection is not permitted, damage to biological resources is minimal. Shell collection which takes live specimens from the intertidal and shallow subtidal zones is destructive to the biological communities.

The areas that are important are those put to multiple use, those used year-round or repeatedly each season, or those that require indigenous biological resources or high esthetic quality to be put to use for recreation.

V. B. 2. b. Harvesting. Harvesting, or the consumptive use of biological resources, is an important consideration when any modification of the environment is proposed. One goal of wildlife and fisheries management is to allow local harvests in designated seasons, often necessitating closure of the area to harvests in other periods in an effort to maximize harvest and avoid overharvest.

Commercial fisheries exist for salmon, bottomfish, oysters, clams, crab, shrimp, and sea urchins. Use of the area by hunters and fishermen is often quite important to local communities in terms of recreation or vacation dollars spent. Some areas lend themselves more to one type of harvesting than another. Nearshore waters near Sequim and open waters throughout the area support large skiff and charter boat fishing activities during major salmon runs. The waters near Dungeness Spit are important for Dungeness crab harvest, while Discovery Bay is more important for bottomfish and clam digging. Intertidal harvesting of invertebrates (e.g., clams) is important in all protected unconsolidated and rocky habitats. Recreational fisheries are important off rocky shores. A substantial harvest of salmon, crab, and herring dominates the commercial fishery off the cobble shore at Cherry Point.

It is difficult to set a standard for assessing the importance of harvesting in a localized area. Perhaps the best approach is to list all known recreational and commercial uses of the area in question, the estimated value of those activities (in terms of dockside value for commercial fisheries and recreational dollars for noncommercial harvests), and an estimate of the effect the proposed action might have on these harvest activities. It remains a subjective judgment of local planners whether the risks to harvestable resources justifies the proposed action. Washington State resource agencies have promulgated various criteria for evaluating the relative importance of areas to clam dredging, aquaculture, and similar activities.

V. B. 2. c. Roosting, resting, hauling out. Many marine animals, particularly pinnipeds and various bird species, require locations for hauling-out or roosting. Availability of these sites is limited, yet they are critical to maintenance of populations. These areas appear to be selected on bases of security or isolation from predation and disturbance, and, perhaps secondarily, for protection from weather and proximity to feeding areas. Many intertidal/subtidal beaches and rock islets are important hauling-out sites for seals and sea lions. Birds roost in nearshore waters, bays, and open water; many rest or roost on beaches near the shoreline. While there may be some flexibility or opportunism shown in site selection, there is apparently considerable tradition involved in site preference and populations or local groups may be critically dependent on availability of specific locations. Only a small group of bird species--loons, grebes, diving ducks, and alcids--appear to be able to, or prefer to, remain on open waters offshore during all resting cycles. While many other birds (dabbling ducks, for example) appear to rest on water surfaces, they also come ashore regularly as do seals and sea lions. Cormorants require both night roosts (often available only at considerable distances from foraging areas) and day roosts near foraging areas for use while drying and preening. Gulls spend much time on-shore betweeen foraging periods, as do the pinnipeds.

Criteria for measuring importance of resting sites are difficult to establish because precise population sizes and location of some nighttime roosts are unknown, and because of the difficulty in comparing the importance of one species with another. In the study area, however, sites used by >25 harbor seals, >10 sea lions, or >500 birds are noteworthy.

V. B. 2. d. Rearing, nursery. Many habitats are important for the rearing and feeding of juveniles (Table 10). Intertidal beaches of the area are used by many species of fish, particularly in the estuaries. Osmerids, embiotocids, and salmonids, for example, rear juveniles in saltmarshes, eelgrass beds, and along protected beaches. These same beaches, as well as the bays, are used by marine birds. Open water is important to rearing some birds and mammals; however, harbor seals in the study area are primarily raised on rock islets and gravel beaches. Invertebrate larvae are ubiquitous and no specific habitat is more important than any other; however, juvenile crabs and shrimps are often very abundant in protected mud/eelgrass habitats.

The following types of sites are important: sites where reproductive activity takes place year-round; sites used year after year by specific populations (e.g., harbor seals); sites where the most sensitive life cycle stages occur in abundance; and sites where a reproductive product (e.g., fish larvae) is important prey for other animals.

V. B. 2. e. Migration. All the intertidal/subtidal habitat types are used by migrants, especially marine birds which use them for resting, feeding, or breeding (Table 10). Sea lions use rock islets as a result of migrations into the area. Juvenile salmonids are common in nearshore waters off mixed coarse beaches in their spring outmigrations. Open waters are important to migrating whales, marine birds, and adult salmon.

The importance of any given geographic area, such as a marsh, bay, or passage, is judged by the importance of the area to the species being considered at the time. The importance of the area to the species is also judged by whether it is unique; that is, if it is lost can the individuals under consideration easily find another suitable area that is not already used to the limit of its carrying capacity?

Important sites for migrants are those that are irreplaceable in the survival of a population, or provide a critical feeding, breeding, resting, or molting area that, if lost, would jeopardize a population. Important sites are those that are used by many individuals representing numerous species or a major portion of the population of a single species. Each species must be looked at individually at each site in question and, then, the species must be considered in total. Total species populations must be kept in mind at all times; the maximum annual total of all individuals that utilize the area must be considered, not just the individuals present at any given time.

V. B. 2. f. Reproduction. Reproduction among the generally sedentary array of benthic organisms occurs wherever the adults happen to be distributed. However, among the marine birds, mammals, and fish, reproduction is often limited to a much narrower habitat when compared to the distribution of adults. The critical habitat characteristic for river otters, harbor seals, and marine birds is the absence of human and other mammal disturbance, usually found on small islands. Many marine fish show a high degree of habitat specificity. The floating eggs of flatfish and larvae of greenling (Hexagrammos spp.) are restricted to the near-surface plankton. Herring spawning is confined in this region to a few, exposed cobble and gravel beaches, while other species such as ling cod spawn at specific subtidal rock nest sites.

The importance of exposed unconsolidated rock and cobble intertidal/shallow subtidal habitats for reproduction is illustrated in Table 10. Sites representing these habitat types which are important are those which have a demonstrable association with specific groups or species reproductive activities; for example, rock beaches and recurring seal pupping (≥ 5 pups per year); bird nesting on upper intertidal and associated uplands of gravel beaches and spits (≥ 50 pairs per year); cobble and other beaches and major herring spawning activities.

V. B. 2. g. Foraging and predator-prey interactions. One of the most important factors determining the extent and structure of the faunal communities of a habitat is the amount of organic material or energy passing through the food web. The critical process in the passage of such trophic energy is, of course, that of feeding or foraging by one organism upon another. Consumer organisms tend to aggregate where the abundance and type (size, shape, mobility) of food organisms are sufficient to guarantee the consumer enough energy for maintenance, growth, and reproduction. Thus, the important habitats and locations are those that support dense and sought-after prey populations and active consumers.

This factor is important at all but two habitats. We have designated habitats as important to foraging based upon both the relative abundance and use by prey and predators rather than upon the basis of the production of food organisms alone, because both are important indicators of trophic energy flow in the area. The principal criteria determining habitat importance thus include habitats which: (1) are characterized by high densities of feeding consumers, (2) possess unique concentrations of prey organisms which are uncommon in other habitats, or (3) have populations of organisms which, through reproduction or immigration, are principally responsible for the recruitment of prey organisms important in adjacent habitats. Examples of the first criteria include habitats which support large flocks of feeding Western Grebes or dense schools of postlarval and juvenile Pacific herring. One example of the second criteria would be a habitat which supports a high standing stock of eelgrass, which is fed upon extensively by herbivorous waterfowl such as Black Brant. An example of the third criteria would be a habitat in which Dungeness crab spawn extensively and provide an abundance of larvae which are transported into neritic waters where they are consumed by planktivorous fishes such as juvenile Pacific salmon.

V. B. 2. h. Detritus production, accumulation, and recycling. As Simenstad et al. (1979) and this volume have illustrated, virtually all of the food webs associated with intertidal/subtidal habitats in northern Puget Sound and the Strait of Juan de Fuca are based primarily upon detrital carbon. While we have little empirical data on the sources of the detritus which enters or becomes available in these habitats, it probably originates from benthic macroalgae, eelgrass, saltmarsh plants, and river-borne terrestrial plants. The fact that the community structure and production of the biota of the region are so dependent upon these detritus sources, and upon the processes which make the detritus available for detritivores, dictates that the habitats involved are of primary importance.

The criteria determining relative importance to overall detritus production include habitats which: (1) produce significant amounts of algal or plant biomass which contribute to the detritus pool (shown in Table 10 as important for plant biomass), (2) are primarily responsible for the physical (mechanical) and biological (microbial/chemical) reduction of large particles to the sizes utilizable by detritivores, (3) accumulate detritus, making it available for accelerated processing, and (4) are characterized by high densities of detritivores or other detritus-processing fauna. As shown in Table 10, the protected habitats having a major mud component are instrumental in detritus cycling.

V. B. 2. i. Benthic faunal biomass. Although for the region as a whole the biomass of marine mammals, birds, and fish is substantial, when expressed per square meter it is very small for all three faunal groups. However, in some habitats the biomass or standing stock of benthic animals can be very high.

In mud, mud-gravel, rock, and cobble habitats (Table 10), the benthic faunal biomass can exceed 1 or 2 kg/m^2. The animals responsible for this high biomass are primarily infaunal clams and epifaunal mussels and barnacles, all animals with heavy shells. Mussel beds can create thick multispecies assemblages on rock and cobble habitats, thus adding a three-dimensional component to communities at these habitats. Sties with frequently observed (several years, each season) faunal biomass values in excess of 500 g wet weight per square meter should be considered as important.

V. B. 2. j. Biomass of plants. As shown in Table 10 plants are primarily important in evaluating rock, cobble, and protected unconsolidated habitats. In benthic communities macroalgae can be important at rock and cobble sites and eelgrass important in protected unsolidated sites. First, they modify the character of the habitat in several important ways. Stands of algae and eelgrass reduce wave and current shock felt by the animal species residing in them. In eelgrass beds, the release of oxygen during photosynthesis may moderate local conditions of low oxygen. Also, intertidal algae retain moisture during low tides, moderating fluctuations in salinity and temperature which occur on bare substrates. The presence of algae adds a third dimension to rock surfaces, which invariably results in a large increase in species richness.

Macroalgae and eelgrass provide a major source of organic carbon to the marine system. This carbon is used directly by macroalgal grazers, and also indirectly, as detritus, by scavengers and detritivorous species.

Few local data on productivity per se are available, either for macroalgae or eelgrass, though Webber (1981) provided growth rate data for two species. Therefore, standing stock of plants is taken here as a very rough indicator of production. Mean yearly values of plant standing stock ranged from less than 1 g/m^2 to over 30 kg/m^2 at the MESA study sites. Values on the order of 1 to 10 kg/m^2 were typical of the low intertidal zones of rock and cobble substrata, where algal cover is at least seasonally high. Subtidal sites with appreciable macroalgal or eelgrass stands also had values in that range. Wet weight of about 1 kg/m^2 or greater can be used as a rough criterion of importance, but factors such as patchiness, seasonal patterns of abundance, and distribution of plants with elevation should also be considered.

V. B. 3. Factors important in evaluating each habitat type.

V. B. 3. a. Intertidal/subtidal zone.

V. B. 3. a. (1) Intertidal/subtidal: exposed mixed coarse. This habitat can be important for foraging, reproduction, rearing, roosting, use by migrant species, and for nonharvesting recreational use (Table 10). This habitat type is characterized by high wave and/or current action, which often results in large movements of sediments.

Dungeness Spit on the Olympic Peninsula exemplifies many of the important features of his habitat. Both phytoplankton and detritus form the base of the food web at this site. Macrobenthos standing stock at Dungeness

Spit was among the lowest at any of the study sites (Nyblade, 1979a), but epibenthic zooplankton densities were not among the lowest compared to other sites (Simenstad et al. 1980). Macrobenthos at other exposed mixed coarse sites may occasionally be dense. At Ebey's Landing, for instance, the intertidal region supported a phenomenal explosion of *Paramoera* sp., a gammarid amphipod, in late spring and early summer, when numbers reached 100,000/m^2.

Large populations of migrating fish in nearshore waters feed upon zooplankton associated with subtidal sediments. The availability of food in proximity to relatively undisturbed shoreline makes Dungeness Spit an attractive roosting site for birds during all seasons, with large numbers of migrants like California and Heerman's Gulls included in the fall. Harbor seals often find this habitat suitable for hauling out, due to the minimum amount of disturbance and proximity to prey. The mixed coarse exposed beaches of Protection Island and Smith-Minor Islands are often important to seals as hauling-out and pupping sites.

Recreational use is important year-round at Dungeness Spit. Beachcombing, bird-watching, photography, and educational activities are all important.

V. B. 3. a. (2) *Intertidal/subtidal: sand*. Importance factors identified at this habitat include nonharvesting recreation, migration, rearing, and reproduction (Table 10). Sites identified as showing these importance factors include West Beach and Eagle Cove.

The use of the sites by migratory birds is similar to other habitats; that is, there is usually an increase in numbers of species in fall and winter seasons. Shorebirds, gulls, and ducks (including Goldeneyes, Buffleheads, Oldsquaw, and Harlequins) are important migratory species. Other migratory birds include the Common Tern and the White-winged Scoter. Seals and some birds may use this habitat type for reproduction.

The sand type of the exposed unconsolidated habitat is important for recreational uses at some sites. Although bird diversity (and, consequently, bird-watching) is lower than at other habitats, the use of sand beaches for recreation is extremely important. The frequent occurrence of backshore dunes and the relative uniformity of the sand substrate through the intertidal and shallow subtidal zones makes this habitat attractive for sunbathing, swimming, wading, and beach walking.

V. B. 3. a. (3) *Intertidal/subtidal: mud-gravel*. Of the importance factors found in this type of habitat, perhaps the most noteworthy are the benthic animal biomass and sport and commercial harvesting. Hard shell clams are responsible for both of these importance factors. Clam biomasses of over 8,000 g/m have been reported for Webb Camp on Westcott Bay (Nyblade, 1977). Mud-gravel beaches are the hard shell clam beaches throughout the region. Sport and commercial harvests represent a multimillion dollar industry in the region.

Other factors important in this habitat are high plant biomass (chiefly Zostera marina in subtidal zones), high detritus accumulation and recycling (Simenstad et al., 1979), high levels of foraging and rearing of young, and high use by migrants. The food webs of mud-gravel habitats are based on phytoplankton and especially detritus. The detritus supports a large community of epibenthic and planktonic crustaceans (Simenstad et al., 1980), which, in turn, are critical food sources for larval fish. These habitats can be crucial nursery areas for a large number of fish species, including several species of flatfish, sculpin, and salmon. The eelgrass of these habitats is a vital food resource of the Black Brant and Wigeon. In addition, the calm waters of the embayments where these habitats are found are very important stopover points for migratory marine birds.

V. B. 3. a. (4) Intertidal/subtidal: mud-sand. Numerous factors of importance are associated with the mud-sand habitat, most notably rearing, foraging, and detritus accumulation; only reproduction and benthic faunal biomass are relatively unimportant compared to the other intertidal/subtidal habitats. Benthic infauna may be abundant, but, due to their small size, they often do not account for high biomass values. Epibenthic organisms can be quite prominent, especially in association with eelgrass (Zostera spp.) beds which are often dense in the more protected areas of the habitat. Perhaps as a result of the linkages to epibenthic crustaceans, there is a coincident abundance of predatory juvenile flatfish, cottids, and various shorebirds, characterizing the middle trophic level consumer organisms. Herbivorous birds (Black Brant, Wigeon) are also commonly associated with the eelgrass beds during periods of their migration through the region or during overwintering.

Several locations exemplify the intertidal/subtidal mud-sand habitats, including Birch Bay and Jamestown. These two sites represent the extremes of this habitat. Birch Bay is the more exposed with coarse sand sediments in many places, sand waves, and sparse eelgrass beds, while Jamestown has sediments with more fines and some extensive, dense eelgrass beds.

Simenstad et al. (1980) illustrated that the Jamestown/Port Williams site had the highest number of taxa, density, and standing crop of epibenthic zooplankton at seven habitats sampled along the Strait of Juan de Fuca in August 1978. Harpacticoid copepods, which are the principal prey of many juvenile fishes rearing in this habitat, were the epibenthic crustacean which dominated the composition of this community. These organisms were associated with the dense eelgrass beds and macroalgae found at this site.

Demersal fish communities are typically of intermediate diversity and standing stock between more exposed habitats and the more protected mud habitat. But, like the mud habitat, juvenile forms of many species, including English sole, sand sole, salmon, and staghorn sculpin, can form much of the demersal fish community in this habitat during the late spring and summer. The apparent association between these juvenile fishes and the eelgrass beds and their abundant epibenthic zooplankton communities is considered to be a function of the accumulations of detritus, abundant prey resources, and refuge from predation.

Bird communities, composed primarily of Glaucous-winged Gulls, American Wigeon, Black Brant, and Bufflehead Ducks, were typically the largest of any habitat, especially in fall and winter months when migrant and overwintering waterfowl foraged and roosted there. Black Brant represent the extreme example; at their peak residency in April over 1,500 brant were observed in the Jamestown area in 1978-1979.

Commercial and recreational harvesting of infaunal bivalves and mobile macroinvertebrates such as Dungeness crab and shrimp is common in this habitat as is the recreational hunting of Black Brant and other waterfowl during the fall months. Nonharvesting uses are typically restricted to bird-watching and beachcombing.

V. B. 3. a. (5) Intertidal/subtidal: mud. Factors that are important include high levels of plant biomass production (particularly of eelgrass), benthic faunal biomass, detritus accumulation, foraging activities, rearing of young marine organisms, migrants, roosting, and harvesting. Interrelationships of factors like these, particularly detritus, eelgrass, and benthic organisms, are often reflected in high species richness and seasonal standing stock levels among many biotic groups. Bottom-feeding and grazing species of birds like Black Brant and American Wigeon are often abundant. This is one of the principal habitats for shorebirds, and at some sites it supports the study area's highest densities of Great Blue Herons which feed upon fish. The protected mud habitats are important for foraging by migrating birds, and are often used by birds for roosting and by harbor seals for hauling out. Harvesting of crabs and bivalves can be important here.

Padilla Bay is an example of this habitat type. Eelgrass beds there are among the most extensive on the Pacific Coast, and this floral biomass, in turn, often attracts up to 50,000 Black Brant during spring migration. Likewise, wintering flocks of American Wigeon are among the largest in the northwest Washington-southwest British Columbia region. Large quantities of detritus accumulate within the habitat, and areas like Padilla Bay may also supply nutrients to adjacent areas through eelgrass detritus drift. In addition to grazers, large numbers of dabbling ducks--scaup, Common Goldeneyes, Buffleheads and scoters--winter in Padilla Bay. Seasonal densities and biomass of birds are usually greatest in winter, though spring biomass is relatively high due to the major movement of Black Brant through this habitat. Glaucous-winged Gulls, which nest on dredge-spoil islands west of the Swinomish Channel, and large numbers of migrant Bonaparte's, Mew, Ring-billed and California Gulls forage on exposed intertidal areas, as do seasonally large flocks of shorebirds, primarily Black-bellied Plovers, Western Sandpipers, and Dunlins. Concentrations of up to 300 Great Blue Herons observed foraging in Padilla Bay (Manuwal et al., 1979) were among the highest counts recorded in the study area.

Padilla Bay serves as a rearing area for invertebrate species. While fish species like salmon inhabit the nearshore water column, the productivity of the subtidal-intertidal zone is reflected in the concentrations of epibenthic-feeding juvenile chum salmon in Padilla Bay.

Large numbers of birds roost on the exposed intertidal areas and on the water surface of Padilla Bay. Harbor seals haul out at low tidal stages on banks of channels at several locations in Padilla Bay, where Everitt et al. (1970) observed a maximum of about 70. The area is used for pupping also.

Harvesting of Dungeness crabs and bivalves is conducted on an important scale, and sport-hunting of waterfowl is a major recreational harvesting activity at Padilla Bay.

Many features of Padilla Bay are duplicated, on a smaller scale, at similar habitats at Samish Bay, Lummi Bay, Birch Bay, Drayton Harbor, and other locations. There are some differences evident in this intertidal/subtidal type at other locations like the Nooksack Delta in Bellingham Bay, or at the Skagit Delta (south of Padilla Bay and outside the study area), where large river inflows lower the salinity of the bays and predominent vegetation shifts from eelgrass to brackish marsh plants like bulrushes (*Scirpus*), sedges (*Carex*), and arrowgrass (*Triglochin*). There is also some shift in faunal species related to vegetation. While Padilla Bay supports one of the largest Black Brant concentrations in North America during the spring migration, very few Snow Geese or swans are observed foraging here. The Skagit Delta is a major wintering ground for Snow Geese and Whistling Swans.

V. B. 3. a. (6) Intertidal/subtidal: exposed rock. Nearly all of the importance factors described for the study area are important to this habitat type with the exception of detritus buildup and use of the habitat as a rearing or nursery area. These two factors are eliminated by the exposure of this habitat to full tidal, wave, and swell forces which effectively remove any detritus materials and make the area unsuitable for fragile juveniles. Dominant organisms in this habitat include large, dense attached algae and invertebrates. This habitat can be important for roosting and breeding by birds and hauling out by harbor seals and migratory sea lions at some sites. Little harbor seal reproduction is associated with this habitat, but invertebrates and fish often reproduce there. Harvesting of mussels, urchins, and fish can be important; and photography, sightseeing, and tide-pooling are common recreational activities.

Tongue Point is an example of an exposed rock habitat for which data were collected during the MESA program. The benthos of this area was composed primarily of macroalgae, gastropods, barnacles, and mussels. The occurrence of these organisms was extremely patchy, though there was little variation from season to season. Marine birds occurred in low nubmers, dominated by Glaucous-winged Gulls. No recent fish data are available from this site and no marine mammals were observed that could be directly associated with this site. Race Rocks are very important to harbor seals and sea lions for hauling out and, in the case of harbor seals, for pup rearing.

The Tongue Point area is important as a foraging area for top carnivores in the study area, including river otters, seals, cormorants; reproduction of benthic epifauna is also important. Many of the birds reported from this area were seasonal migrants. Aerial shoreline censuses in the rock area between Tongue Point and Observatory Point recorded relatively low densities of birds, though large numbers of gulls were occasionally observed during migrations and winter.

Harvesting by recreationalists is limited to collection of mussels, though some surf and spear fishing may occur. Tongue Point is attractive to nonconsumptive users who may find the wild coastline and dramatic surf appealing. Beachcombing, photography, tidepool observing, and bird-watching can provide satisfactory diversions to the vacationer.

V. B. 3. a. (7) Intertidal/subtidal: protected rock. All of the factors that make exposed rock sites important also apply to protected rock. Rearing, in addition, can be important as harbor seals and some birds use protected rocks in the San Juan Islands for the rearing of young. Macroalgae and dense, shelled invertebrates contribute to a high algal and benthic faunal biomass at important areas. Foraging by nearshore fishes, reproduction and rearing by harbor seals and some birds, hauling out by harbor seals and migratory sea lions, harvesting of invertebrates and fishes, and recreation can be important.

Point George and Fidalgo Head are examples of this habitat type. Numerous molluscs (mainly gastropods), crabs, and echinoderms were found on subtidal rock at Point George, which is a biological research preserve. The kelps Alaria and Nereocystis were common there, as were intertidal fishes.

Harbor seal pupping activity may result in 10 to 30% of a population consisting of pups on protected rocks. Northern sea lions are often found on protected rocks in the San Juan Islands; they are among the most important migrants to use this habitat. Various ducks, scoters, alcids, and gulls frequent important protected rock habitats during their migrations and foraging activities.

Harvesting of kelp bed fishes, mussels, and urchins occurs where these resources are dense. Recreational activities such as sightseeing, photography, and educational field trips are common.

V. B. 3. a. (8) Intertidal/subtidal: cobble. This habitat at some sites is important to harvesting and nonharvesting activities, roosting, migration, rearing, foraging, and reproduction of benthic faunal biomass and algal biomass. The cobble nature of the bottom allows for the attachment of many organisms which, in turn, provide habitat and living space for other organisms.

Cobble beaches are at times utilized by birds, especially gulls, for roosting. Harbor seals also utilize this habitat for hauling out. During their migrations, gulls and ducks use this habitat for short stays to feed and roost.

At the Cherry Point site, annual spawning of Pacific herring attracts commercial harvesting operations in adjacent nearshore waters in the spring. This spawn, a very large one, also attracts large numbers of birds that feed upon the eggs. Fish are also attracted to the large volume of food available. Birds attracted to the spawn include large numbers of scoters and gulls.

The algal and invertebrate benthic biomass measured at Morse Creek was consistently among the highest of any of the sites. Nyblade (1979a) observed up to 15,000 organisms/m^2 and over 3,000 g/m^2 at the 0' tidal elevation. Barnacles, molluscs, and macroalgae were dominant. Intertidal fish density, species richness, and abundance among the Morse Creek cobbles were comparable to those of other sites (Miller et al., 1980). Harvesting of intertidal invertebrates and fishes takes place at Morse Creek and Cherry Point. Subtidal commercial crabbing occurs at Cherry Point. Educational field trips and recreation are common due, in part, to the abundance of marine organisms.

V. B. 3. b. Nearshore.

V. B. 3. b. (1) Nearshore: exposed mixed coarse. Migration and roosting are important uses of this habitat for many fish and bird species, respectively. Substantial seasonal migrations of both adult and juvenile salmonids occur. Large concentrations of Pacific herring and sand lance are common. Fish densities at Dungeness Spit, for example, were among the highest found at any of the sites.

Many bird species migrate through this habitat in large numbers. California, Bonaparte's, and Heermann's Gulls, Bufflehead, Surf Scoters, Rhinoceros Auklet, Common Murres, various loons, and cormorants all use the area during migration. The alcids, loons, and cormorants may spend more time in deeper water offshore during migration. Gulls and alcids roost on the water in this habitat, although alcids may prefer deeper water, and the gulls may roost on nearby exposed beaches much of the time.

V. B. 3. b. (2) Nearshore: sand. Importance factors recognized for this habitat include migration and foraging (Table 10). West Beach is one site having these characteristics.

As with other habitats, bird species are important migrants. Some species (i.e., the Mew and Thayer's Gulls) are only commonly found in spring and fall during their northerly and southerly migrations. Other species are commonly found during fall and winter and move north or inland in spring and summer. Species having this type of migration include Western Grebes, loons, cormorants, alcids, and mergansers.

Fish species are also important migrants. Juvenile pink and chum salmon are found in the nearshore waters of the sand habitat during spring and summer. Adult Pacific herring are found from December to June preparing for reproduction. Juvenile herring are common in the summer and move offshore during the fall.

The use of this habitat for foraging has been noted for birds, mammals, and fish. Both harbor porpoises and killer whales can be expected to use this habitat for feeding. Birds seasonally foraging include the Horned Grebe, Arctic Loon, and Common Murre. Juvenile Pacific cod may be found feeding during their first year. Adult spiny dogfish, ratfish, and some cod may move into this habitat at night to feed.

Two important juvenile fish seasonally forage off Eagle Cove (Miller et al., 1978). Pink salmon are abundant from June to August, feeding primarily on calanoid copepods, harpacticoid copepods, and gammrid amphipods. Silver salmon may be found commonly from April to October feeding primarily on drift insects, although zooplankton (i.e., zoea and megalops) and epibenthos (i.e., gammarid amphipods) are also used for food.

V. B. 3. b. (3) Nearshore: mud-gravel. Mud-gravel habitats are typically found along the sides of large embayments, such as at Beckett Point in Discovery Bay and in small embayments, such as Webb Camp in Westcott Bay on San Juan Island. The nearshore area of these mud-gravel habitats may be important for roosting, rearing, and foraging (Table 10). The water column is a rich foraging area for nearshore fish, seabirds, and mammals.

The high primary productivity of these embayments may support high secondary production of nearshore zooplankton in important sites. This community, in turn, serves as the food resource for rearing postlarval sand lance, surf smelt, and herring. Fish-eating birds (grebes, guillemots, cormorants, loons) and harbor seals are supported by rich secondary production.

Some large embayments such as Discovery Bay serve as very important roosting areas for a variety and high density of migratory and resident marine birds. Manuwal et al. (1979) found up to 9,000 birds roosting in Discovery Bay.

V. B. 3. b. (4) Nearshore: mud-sand. Important characterisics of the nearshore waters at the mud-sand habitat include roosting, rearing, and foraging. As described for the intertidal/subtidal habitats, the nearshore waters associated with mud-sand habitats characteristically occur in semiprotected regions of embayments. The importance of this nearshore habitat is associated with characteristics common to all embayments. Due to the usually increased water stability and nutrient sources entering such embayments, the water column primary productivity tends to be higher and occur earlier in the year than in colder, more mixed water masses. Detritus sources in the marsh, riverine, and eelgrass habitats common to embayments also tend to contribute to this increased productivity through the generation of dissolved organics and other nutrients important to phytoplankton production. This increased primary production is directly linked to the secondary production of neritic zooplankton, which, in turn, support high standing stocks of consumers during certain times of the year. This linkage results in a distinctive association of zooplankton-eating fishes and fish-eating seabirds which forage and rear their young in this habitat from winter through late spring and early summer. Postlarval and juvenile Pacific herring, surf smelt, and Pacific sand lance constitute the principal zooplankton-eating fishes which are observed to aggregate in these habitats, especially when they are in proximity to the intertidal/subtidal mud-sand and eelgrass habitats where reproduction of these species occurs. Fish-eating birds common to this habitat include Western and Horned Grebes, Pigeon Guillemot, Pelagic Cormorant, and Common Loon.

The neritic waters adjacent to the Jamestown site provide an example of the nearshore mud-sand habitat. Catches of postlarval Pacific herring, surf smelt, and Pacific sand lance as high as 0.65, 0.09, and 0.05 fish/m^3, respectively, were documented in spring tow net collections at Port Williams (Miller et al., 1980). The most prevalent fish-eaters in the Jamestown region during spring were Western Grebes and Red-breasted Mergansers. Bird densities of 1,000 to 2,000 birds/km^2 and projected total counts of up to 46,000 birds roosting or swimming in the Jamestown subregion were recorded in winter (Wahl et al., 1981). In early summer, Pigeon Guillemots occurred prominently in the region and may be directly associated with the habitat through their foraging upon sand lance migrating through the neritic waters adjacent to the intertidal/subtidal eelgrass beds. Foraging by seals on fish was important at Jamestown.

V. B. 3. b. (5) Nearshore: mud. Important characteristics of the nearshore waters of protected, mud habitats include foraging by many species, rearing of young fish, and use by birds for roosting. Many of the processes and activities taking place in the water column relate both to the relatively protected nature of embayments and the productivity of underlying subtidal and intertidal habitats.

This mud-eelgrass-detritus trophic base supports abundant plankton which are prey for a wide range of small fish, including many resident and migrant species, particularly juvenile chum salmon. This trophic base may, in turn, support sizable populations of fish-eating harbor seals and birds such as loons, cormorants, mergansers, and opportunistic gulls in important areas. Water-column plankton include larvae of many benthic forms, and concentrations of drifting larval forms of fish, barnacles, and other organisms.

Padilla Bay exemplifies this habitat type in the study area. In addition to large populations of resident fish species, its nearshore waters serve as rearing habitats for juvenile salmonids, Pacific herring, and sand lance, and as winter foraging habitat for large numbers of Common and Red-throated Loons, Red-necked, Horned and Western Grebes, Double-crested Cormorants, and Red-breasted Mergansers. The winter average of about 300 Double-crested Cormorants (Manuwal et al., 1979) represents one of the largest foraging concentrations of the species in the study area. Groups of up to 70 harbor seals (Everitt et al., 1980) observed hauled out at low tidal stages in Padilla Bay presumably also forage at least part of the time in the water column here.

The nearshore habitat is important as a roosting area for the birds discussed above, and also for thousands of ducks and geese which are resident from fall through spring. Average winter flocks of about 80,000 waterfowl which forage in intertidal/subtidal habitats also rest on the surface of the bay. Because seasonal averages understate presence of species showing abrupt occurrence peaks, the spring season estimate given in Manuwal et al. (1979) does not truly reflect the importance of Padilla Bay in this season when up to 50,000 Black Brant may be present at one time. Padilla Bay thus serves as an important roost both for birds using the nearshore wawter column and for birds using intertidal/shallow subtidal foraging habitats. This roosting activity is likely due to the high degree of protection offered in the embayment from effects of weather, security from predation, and minimal human disturbance (likely due in part to shallow water depths).

V. B. 3. b. (6) Nearshore: exposed rock. Because of the limited information on this habitat, only a few important factors were identified as being significant in this habitat. They include: foraging, harvesting, and nonharvesting (nonconsumptive use).

An example of nearshore exposed rock for which recent biological information has been collected is Pillar Point. This area has limited value as a roosting area and bird densities are quite low. Manuwal et al. (1979) reported densities for all species of less than 200 birds/km^2 for the subregion along the coast that includes Pillar Point. Foraging nearshore fishes were abundant in tow net catches, dominated by Pacific herring. Fish densities were greatest in summer months (1.66/m^3) (Miller et al., 1980). This abundance and diversity of fishes may make sites such as this important foraging areas for marine mammals. However, few marine mammals records are available for this site.

Recreational sport fishing undoubtedly constitutes the most important human use of this habitat though diving and surf fishing may also occur. Nonconsumptive uses include photography and bird-watching. This portion of the Olympic Peninsula attracts many vacationers.

V. B. 3. b. (7) Nearshore: protected rock. The nearshore protected rock habitat may be important for the same factors at exposed rock: foraging, harvesting, and recreational activities. These factors are related to the rock/kelp bed physical structure and to the relatively low wave and current action.

Point George is a site representative of this habitat type. Miller et al. (1978) showed that fish densities there were relatively high (mean of 0.29 fish/m^3) in tow net catches. Mean standing crop values were relatively high also, but were lower than those at protected mud-eelgrass habitats, reflecting the small size of the dominant species at Point George. Foraging by sand lance, Pacific herring, and kelp bed fishes appears to be important at this site.

Harvesting of kelp bed fishes such as sea perch and greenlings by hook-and-line and diver can be important at protected rock sites such as Point George. Many of the species found at this habitat type avoid tow nets and thus do not appear in catch statistics. Nevertheless, they are attractive to fishermen. Nonharvesting recreational activities such as sightseeing, diving, and photography may be important at sites having this habitat type.

V. B. 3. b. (8) Nearshore: cobble. This habitat is important for harvesting and nonharvesting activities, roosting, rearing, and foraging. An example of this habitat type is Cherry Point.

As for the intertidal/subtidal cobble example, the annual herring spawn is of significance at some sites having this habitat. Part of this spawn is harvested in nearshore waters by commercial fishermen, while the bulk is left to develop or to be eaten by various predators, including fish, scoters, and gulls. Other diving birds are often associated with the feeding activities. These include, especially in the winter, loons, grebes, alcids, and cormorants. Gulls are always found in the area, but are confined to the surface layer of the water column in their feeding activities.

The nearshore waters of cobble beaches are foraged by seals and often used for roosting by various diving ducks, gulls, and other diving birds. These birds often spend the night on the water.

The foraging activities of nearshore fishes such as herring were reflected in the relatively high tow net catches at Cherry Point. Though highly variable and seasonal, tow net catches there averaged 0.05 fish/m^3 and 0.13 g/m^3 with some catches exceeding 2.6 fish/m^3 and 5.6 g/m^3 in summer (Miller et al., 1978). The dominant species was Pacific herring.

Rearing of the herring that hatched nearby constitutes an important activity in some sites, including Cherry Point. The major harvesting activities are related to the herring and salmon populations at this site, while recreational activities include boating and sightseeing.

V. B. 3. c. Offshore

V. B. 3. c. (1) Offshore: broad passages. Activities that can be important in this habitat are foraging, migration, rearing, and harvesting. Since emphasis in the MESA and WDOE studies was on the intertidal/subtidal and nearshore habitats, little data exist for this habitat.

Admiralty Inlet exemplifies the broad passage habitat. Admiralty Inlet is a broad passage and it marks the water exchange area between central Puget Sound and the Strait of Juan de Fuca. It is often marked by strong tidal currents and convergences with obvious turbulence.

Commercial harvesting and sport harvesting of salmon is a common activity in the passage area. Summer run king salmon are captured by gill net and purse seine. Blackmouth (resident chinook salmon) and coho salmon are also pursued by sports fishermen.

Because this is the passage between two major water systems, it is the scene of migrations within the study area and between other Washington waters. Birds commonly fly up and down the passage as they change areas of foraging activity. During the summer months Rhinoceros Auklets are seen flying daily through the passage. Marine mammals such as harbor seal, Dall's porpoise, and killer whale utilize the area for passage to and from the Puget Sound central basin. On a larger scale, birds passing through the study area on migration are noted in the passage seasonally.

Foraging by birds commonly is observed in the passage, especially by large feeding flocks consisting of alcids, gulls, and cormorants, which are often seen associated with the tidal fronts. The activity of these birds is constantly changing as the currents ebb and flow in the passage. Foraging activity by migratory salmon and predatory mammals such as killer whales is important in this area.

Some larval stages of fish which occupy intertidal and nearshore habitats as adults are reared in these waters as members of the near-surface ichthyoplankton. Some marine mammal juveniles can be abundant there.

V. B. 3. c. (2) Offshore: narrow passages. Narrow passage habitats often feature very strong tidal currents, and factors of importance relate to concentrations of plankton borne by currents and on nekton. Plant (phytoplankton) biomass, foraging, migration, and harvesting can be important. Some of the highest observed densities of foraging birds within the study area were recorded in this habitat, though it is dramatically apparent that foraging activity varies greatly, depending on tidal stage and season. Densities and estimated populations given in Manuwal et al. (1979) are mean seasonal averages and do not represent peak usage which may be 100-200% greater. In addition, concentrations of sea lions are often observed in this habitat type.

Because of their biological features, narrow passages are important to migrating fish, mammals, and birds, in addition to resident animal populations. The concentrations of many species are related to tidal stage and, thus, are recurring features; and they consistently attract predator species which migrate through the study area or winter there. The narrow passages are also notably important for one popular form of harvesting recreation—sport-fishing for salmon. Food webs are structured around phytoplankton and productivity may be very high in these passages; advection of prey animals by tidal contents may also be responsible for pelagic plankton-eating concentrations in this habitat.

Speiden Channel and Active Pass illustrate the biological importance features of narrow passage habitats and also variations between these passages. Speiden Channel's offshore waters (>20 m depth) had highest bird densities in fall ($89.0/km^2$) when migrating small gulls and terns represented most birds present, and in winter ($84.8/km^2$) when loons, cormorants, gulls, and alcids accounted for foraging populations. Many birds observed in fall (Bonaparte's Gulls and Common Terns) primarily eat small fish or plankton, while abundant wintering species like Arctic Loon, cormorants, Mew Gulls, and Common Murres are larger in size and presumably feed on larger-sized prey.

Active Pass is narrower and its strong tidal currents attract very large foraging flocks of birds. Average densities in spring 1978 were $674.8/km^2$, and the winter average was $383.8/km^2$. These included censuses during "slack-water" periods when bird activity was low. While Bonaparte's and Mew Gulls, which feed upon zooplankton, often were present in large numbers, the great proportion of the biomass consisted of birds of two piscivorous species, the Arctic Loon and Brandt's Cormorant. The spring and winter concentrations of these two species in Active Pass were relatively consistent and were among the highest recorded in the study area. Herds of up to 30 Steller's or California sea lions were also consistently found in Active Pass in the winter-spring seasons, and killer whales are regularly observed there. Active Pass is also well-known as one of the most productive salmon sport-fishing locations in the region due to the use of this passage by migratory salmon.

Similar situations and importance factors, with variations in magnitude and species, are found at other narrow passages in the study area, in particular, southern San Juan Channel near Cattle Point and Deception Pass and, on a lesser scale, Thatcher Pass and Obstruction/Peavine Passes.

V. B. 3. c. (3) Offshore: bays. This habitat type encompasses the deep (>20 m) water of bays. Available biological information for offshore habitats is limited to bird and mammal data. Phytoplankton production and biomass can be important in this habitat, since the contribution of attached plants to total production is minimal. Conditions such as water column stability, insolation, and nutrient inputs are optimal for phytoplankton. This habitat can be important as a foraging, rearing, or nursery area for some species; a roosting area for birds; and for use by both nonharvesters and harvesters.

An example of an offshore bay habitat is Bellingham Bay. This bay is quite large and has a sizable offshore component. This area is notable for the large percentage of Western Grebes found there, which is by far the most abundant bird species drawn to forage upon the rich fish fauna. This and other common species which roost on the open waters are loons, grebes, gulls, and Common Murres. Bird densities exceeded 258/km^2 in our surveys, and total abundance has been estimated at 32,000 birds (Wahl et al., 1981).

Everitt et al. (1980) reported harbor seals in Bellingham Bay on a few occasions but in small numbers. The difficulty in counting seals from the air in an area of high human disturbance may have accounted for these low numbers since several haul-out sites known to local residents were never observed with seals during aerial surveys. Balcomb et al. (1979) speculated that local pods of killer whales can be expected in this area during fall salmon runs. Other cetaceans observed in Bellingham Bay include gray whales (rarely), minke whales, and harbor porpoises.

Bellingham Bay is undoubtedly important as a rearing area for juvenile salmon, though no data were collected in this study to verify this assertion. Nonconsumptive users can be found in Bellingham Bay engaged in a variety of recreational pursuits, probably the most obvious of which is sail and motor boating. The bay provides a valuable commercial fishery and is heavily fished by local salmon gill-netters during peak runs. An active sport fishery also occurs; greatest activity is often found on the outer reaches of the bay.

V. B. 3. c. (4) Offshore: open. Open water represents a very large component in the study area. However, little biological data were collected there. Factors of importance to this habitat include foraging, rearing, migration, and roosting by many species and harvesting by commercial and sport fisheries.

The Western Strait of Juan de Fuca is an example of this habitat. The major foragers and migrants through the area are mammals, birds, and salmon. Marine bird densities in this area were quite low during most of the year. Common Murres roosting on open waters comprised the largest component of bird fauna for any season with greatest densities observed in the fall when a total of up to 140,000 were observed. Fall is the season when densities of all species of birds were the greatest, exceeding 89 birds/km^2; in the spring as few as 4 birds/km^2 were observed (Manuwal et al., 1979). Cetaceans utilize the open water areas exclusively and may be more abundant in the western Strait than any other location in the study area (Everitt et al., 1980). Essentially, the entire population of gray whales migrates through the offshore waters at the mouth of the Strait during north and south movements. Dall's porpoise may also occur here frequently. Few harbor seals are found in this area, but sea lions (northern and California) must pass through this area during the postbreeding season (fall and winter) movements into Puget Sound.

This area is important for rearing many fish species, as indicated by the abundance of fish eggs and larvae in plankton samples. Chester et al. (1980) found 49 taxa of eggs, larvae, and juveniles in ichthyoplankton samples, 15 of which were of commercial value (e.g., salmon, sole, smelt, greenling, herring, cod, and ling cod). Greatest densities were recorded in late winter and early spring. The authors estimated as many as 100 million fish eggs may occur in the Strait at any one time.

Sport fisheries are active in this area keying in on migrating salmonids and assorted bottom fishes. Commercial fisheries, primarily for salmon, are equally important.

V. C. Ecological Relationships.

V. C. 1. Habitat-to-habitat relationships. Although this report considers habitats to be separate and identifiable entities, it is important to note that they all belong to a single ecological system and that there are many functional linkages between habitats. Also, many human activities often affect more than one habitat either directly or indirectly. Perhaps the best example of this is the flow of biological energy through habitats. Rock and cobble habitats, as well as those protected unconsolidated habitats that have eelgrass beds, are energy exporters. That is, algae and plankton tissue is dislodged by natural die-off and wave action and is carried by currents to other areas. As this plant tissue is mechanically broken and degraded into detritus, it is an important source of food to organisms in other habitats. Although this detritus does not accumulate on exposed gravel and sand beaches, sites having these habitats may support large amphipod populations such as those seen at Ebey's Landing and Deadman Bay. Detritus tends to accumulate in protected unconsolidated habitats where it is an important source of energy to the total faunal community. The intertidal/subtidal food web at the protected Jamestown site, for example, is detritus-based; and the sources of detritus are located both nearby and far away.

Reproduction of many species bridges the boundaries between habitats. Many species of benthic invertebrates have planktonic larvae that spend some time as pelagic forms in the nearshore and offshore habitats. Some fish species move from deep to shallow water to spawn. The eggs and larvae of cod, ling cod, greenlings, sole, herring, and smelts occur in abundance in open water but may either spawn or live as adults in nearshore or subtidal habitats. Salmon use the offshore habitats for adult migration and the intertidal and shallow subtidal zones for feeding and protection of the juveniles. Birds (i.e., the Glaucous-winged Gull) nest only on undisturbed areas but may feed at many different habitats. Rhinoceros Auklets nesting on Protection Island fan out to the Puget Sound central basin, Admiralty Inlet, and elsewhere daily to feed. Similar movements of harbor seals through a variety of habitats for feeding, hauling out, and reproduction have been observed.

Though many of the sites sampled in the MESA and WDOE studies were clearly representative of one habitat type, some showed the influence of other nearby habitat types. Point George (rock) was near a bay; the Morse Creek beach seine site (gravel) was near cobble; Twin Rivers (gravel) was near two streams and protected offshore by a cobble/kelp reef. Thus, biological data collected at these sites represented inputs from more than one habitat type.

The ecological linkages among species and the patterns of utilization of various habitats are complex. Any consideration of the structure and function of a single habitat must include linkages with other habitats.

V. C. 2. Importance of each habitat to total system. Habitats in this report were defined primarily on a physical basis. The definitions of habitats are directly relevant only to those species which are directly dependent upon the physical characteristics, and indirectly relevant to those species which are present as a function (result) of the presence of other species of plants and animals.

Each habitat type means something different to each species. For one species a habitat may be important as a source of food, while to another it is a breeding or roosting site, and so on. The matrix of habitats and life support activities (e.g., foraging, reproduction, rearing of young) for each species differs among species. It can differ in terms of the number of habitats that are used in each activity and in the relative importance of each habitat. Some species may conduct all of their life support activities at only one habitat, while others may conduct each activity at several habitats. These former species would be considered to have narrow ecological relationships, while the latter species would be said to have broad ecological relationships.

The collection of physical habitats and processes and the species loosely or closely associated with each make up the ecosystem of the study area. Because some species have very specific or physical requirements, their abundance and distribution in the area are a direct function of the abundance and distribution of their required habitat. Thus, a species of narrow requirements with only limited habitat available will be necessarily rare or common only where the appropriate habitat requirements are met. The habitats that support the greatest number of species, greatest biomass, and greatest energy flow are often the most important. Further, one can look at the importance of a habitat from its contribution to the maintenance of species in other habitats; i.e., it is a net exporter of reproductive products, material, and/or energy.

From the discussion above it is apparent that the biological components of the ecosystem are dependent upon all habitats. No community associated with a habitat type functions in a vacuum entirely dependent on just one site representing a single habitat type. It follows, then, that the loss of any area would not only affect those biota at that site, but possibly those associated with other habitats at other sites.

The importance factors and examples discussed above address each habitat type individually as if they were not interrelated. Of course, this assertion is not true. The reader must appreciate that while the nature of the interrelationships may be poorly understood or nonquantified, these relationships do exist and are often important.

V. C. 3. Importance of study area to Northeast Pacific. The importance of the study area to the biota of the northeast Pacific and adjacent provinces became apparent during many of the studies. Though no studies were performed to specifically characterize the relationship of the study area to adjacent or larger systems, several examples are noteworthy.

The relatively protected nature of the study area lends itself to providing important habitats for juveniles and breeding adults of many species. These waters are situated near (between) the boundaries of boreal/sub-Arctic and subtropical waters, and as such its fauna is rich, including species of both areas. For many species of fish, birds, and mammals, these waters provide a place to pause during northward or southward migrations.

Five species of salmon move through these waters during two phases of their life cycles. Adults move into the protected waters from the open ocean enroute to spawning streams and large runs occur at all seasons of the year. After spawning and hatching, smolts move into the study area and eventually enter open ocean waters. The contribution of Puget Sound salmon to the North Pacific pool is large. Adult herring also move in and out of the study area from northeast Pacific waters for spawning purposes. It is unknown what contribution this spawning population makes to the oceanic herring stock.

The inland waters of Washington provide a rearing area for larval and/or juvenile forms of sablefish, yellowtail rockfish, and, perhaps, other related species. Adults of these species move into oceanic waters before becoming sexually mature, and all spawning takes place in the ocean. The adults remain offshore, but juvenile forms enter the Puget Sound region until they too approach sexual maturity.

The study area is important as a wintering area for migratory marine birds that nest in other coastal or inland areas. An example is the Common Murre which is abundant in the inside waters of the Strait in fall and winter and which return to breeding areas along the open coast from California to

Alaska in spring and summer. Other species exhibiting similar use of the study area include Western Grebes, Arctic Loons, Brandt's Cormorant, Oldsquaw, and Mew and Thayer's Gulls.

Manuwal et al. (1979) identified the Rhinoceros Auklet as comprising approximately 60% of all breeding birds in the study area. Of the nearly 18,000 pairs of Rhinoceros Auklets, most breed on Protection Island. This large breeding concentration represents a significant proportion of the entire northeast Pacific population of Rhinoceros Auklets.

The importance of the study area to northeast Pacific populations of most cetaceans is unclear. Most species occur here rarely or accidentally. Of the common species only the gray whale and killer whale occur in appreciable numbers. Essentially, the entire population of gray whales passes through the extreme western reaches of the study area during its northward migration in the late winter and spring and southward migration in the fall. This endangered species is the largest remaining population of baleen whales in the northeast Pacific.

California sea lions migrate into the area in the late fall and winter from California and adjacent areas. Nearly 300 animals have been observed in November in the study area. Northern sea lions also migrate into the area during late fall and winter, though usually in lower numbers than the California sea lion. Northern sea lions breed in coastal locations of California, Oregon, British Columbia, and north to the Bering Sea. California sea lions breed along the coast of California and Baja.

No benthic invertebrates or plants are endemic to the study area. The inland protected habitats provide a contribution to the total gene pool of the coastal northeast Pacific waters. Many soft bottom infauna and rocky intertidal epifauna common in the area are also found along the coast and in other inland areas north into Alaska and south at least to Point Concepcion.

Open ocean zooplankton have been observed entering the Strait during strong onshore winds associated with storms. These organisms, while not normally excluded from the Strait, become very concentrated during these events. Their entry into the Puget Sound central basin has not been documented.

V. C. 4. Unique features. During the studies that were performed under the MESA and WDOE programs, the investigators observed biological features of the study area that were unique and noteworthy. These are listed and briefly discussed below. This list is not comprehensive. It is not explicitly meant as a list of important features (biologically, socially, or politically), though this conclusion is implicit. Such an explicit evaluation of relative importance for all biota is not possible, since the data base is neither complete topically nor geographically. The list has not been formulated in any particular order.

V. C. 4. a. Protection Island. Over 19,000 of 30,000 pairs of breeding birds in the study area were found there. Total counts of over 8,000 birds were recorded along the shoreline. Eagle nests were found on the island. Average monthly counts of nearly 150 harbor seals were recorded; a maximum of 223 were observed at one time. The second largest breeding population of harbor seals was found there. Nearby Dallas Bank supports an important kelp bed and foraging area for predators.

V. C. 4. b. Smith-Minor Islands. A maximum of 44 harbor seal pups was observed there, making this the most important pupping site in the study area. Monthly counts of harbor seals averaged about 150; a maximum of 257 were observed at one time. About 850 pairs of breeding birds were recorded.

V. C. 4. c. Race Rocks. Combined counts of over 300 California and northern sea lions were made for this rocky isle in the winter. Monthly counts of harbor seals in a coastal area of Vancouver Island that included Race Rocks averaged about 200; a maximum of 504 were counted in August.

V. C. 4. d. Dungeness Bay/Dungeness Spit/Jamestown. Dungeness Spit is a National Wildlife Refuge. A maximum of nearly 5,000 birds occurred along the shoreline of the spit. Another 200 birds were observed breeding in the Dungeness Bay/Jamestown area. Nearly 55,000 birds have been observed along the shoreline in the latter area, the largest concentration of marine birds recorded along the shorelines of the study area. The highest Bird-Oil Index values were calculated for the Jamestown subregion, indicative of the density of birds and their sensitivity to oil. Monthly counts of harbor seals averaged about 50; a maximum of 119 were observed in August. Over 50,000 infaunal organisms/m^2 were found at Jamestown. Beach seine collections were species-rich and high in biomass. Epibenthic zooplankton samples taken in eelgrass at Jamestown exceeded those taken elsewhere in biomass by at least an order of magnitude. Juvenile salmon were abundant in beach seine samples taken on the exposed side of Dungeness Spit and at the Jamestown site.

V. C. 4. e. Padilla Bay. This bay has been designated as a National Estuarine Sanctuary. The broad mudflats support dense infaunal benthos and eelgrass. Projected total estimates of up to 90,000 birds along the shoreline and in the water have been calculated for the bay, the majority being found in the water. As many as 95 harbor seals have been observed hauled out on mudflats at low tide; the area is important for pupping. Samish Bay and the undeveloped portion of Bellingham Bay share many of the same characteristics as Padilla Bay.

V. C. 4. f. Slip Point to Pillar Point. Mean total biomass for intertidal epibenthos was very high along this rock bench. At the 0' tidal elevation, over 11,000 g/m^2 were recorded, the highest value observed along the Strait. Species richness was also high (over 120 species) among epibenthos sampling sites.

V. C. 4. g. Admiralty Inlet. Average projected estimates of over 7,000 birds were calculated for this area; many species are known to be susceptible to the effects of oil. Killer whales, minke whales, northern elephant seals, and harbor seals transit the inlet to and from Puget Sound and probably forage there. Salmon migrating to and from Western Washington streams transit the area also. Foraging by over 12,000 birds in the turbulent waters at one time in this area has been observed.

V. C. 4. h. Cherry Point. The highly important herring spawn activity in February/March is reflected in a considerable commercial fishery, high-density tow net catches, and a seasonal influx of marine birds. Up to 24,000 birds, 22,000 of which were scoters, were observed in the spring.

V. C. 4. i. Western Strait of Juan de Fuca. Total estimates of Common Murres of up to 140,000 in the fall have been calculated for these open waters; exceptionally high Bird-Oil Index values accompany these counts. Cetaceans such as gray, minke, and killer whales occur there periodically, as do Dall's porpoise.

V. C. 4. j. Discovery Bay. A high species richness of birds and projected total counts of up to 18,000 birds have been recorded. Mean species richness values of up to 30 species of fish were observed for beach seine samples taken at Beckett Point, the highest recorded for the Strait. Fish abundance and biomass were consistently very high. Epibenthic zooplankton abundance and biomass were exceeded only by those data from Jamestown. A major commercial clam bed exists along the shoreline of Discovery Bay. Mean total abundance of benthos at the 0' tidal elevation equalled nearly 60,000 organisms/m^2, rivalled only by that of the Jamestown site. Species richness and biomass were also relatively high.

V. C. 4. k. Southern Lopez Island and vicinity. Projected total estimates of up to 11,000 marine birds were recorded. Nearly 2,000 pairs of breeding birds were observed in the area. Up to 32 harbor seals were seen on Mummy Rock near Lopez Island. Northern sea lions were also seen there and in Middle Channel. Considerable epibenthos were associated with the exposed rock habitat. Killer whale migratory routes through the San Juan Islands and the eastern Strait converge in the area immediately south of Lopez Island.

V. C. 4. l. Tatoosh Island. Nearly 2,200 breeding pairs of marine birds were seen on this island, the second most important breeding colony in the study area. Projected total estimates of up to 17,000 birds were made for the area along the shoreline and on the island. Some harbor seals and as many as 55 northern sea lions have been seen on Tatoosh Island. Epibenthos on this exposed rock is probably abundant and dense.

Other areas having unique features outside or bordering the study area have not been listed, though the large salmon runs into the Fraser River and bird populations throughout the Canadian Gulf Islands and in Boundary Bay, Skagit Bay, Port Susan, and Penn Cove are well-known.

VI. POTENTIAL INTERACTIONS OF HABITAT TYPES AND KNOWN OR PROPOSED TYPES OF PERTURBATIONS

VI. A. Summary of Present Pollution Status

The study area has been and remains relatively free of pollution. The majority of the shorelines bordering the study area are unpopulated or sparsely populated. Except for isolated areas near Seattle and Tacoma in the adjacent Puget Sound basin, the assimilative capacity of the marine ecosystems generally has not been exceeded (Goldberg, 1979). Urbanization and industrialization have primarily occurred near estuaries and embayments (e.g., Port Angeles, Friday Harbor, Bellingham, Anacortes). Some local historical, existing, and/or potential problems have been identified, however, and are discussed briefly below.

A large variety of pollutional stresses conceivably could take place in the study area. The categories addressed below are those considered by the authors to be most important in the study area relative to their historical, existing, or potential impacts.

VI. A. 1. Oil spills and other industrial accidents. Two large spills have occurred in the study area. One, a spill of 5,000 gallons of crude oil off the ARCO dock at Cherry Point in 1973, was not studied, and its effects on the marine environment are not known. The second was a 200,000 gallon diesel fuel spill from the Texaco dock at Anacortes in April 1971. The initial mortality from this spill was evaluated, primarily west and north of the spill site. Localized areas showed extensive mortality of surface invertebrates, algae, and infauna. Some nemerteans, polychaetes, clams, snails, barnacles, limpets, and sea cucumbers suffered substantial mortalities; some recovery was observed six months later in gravel and cobble beaches (Woodin et al., 1972). No studies of impacts on fish, plankton, or birds were conducted, nor was any long-term damage assessment made. Effects from a small but persistent spill of Navy Special Fuel Oil residue upon intertidal biota near Cape Flattery were restricted to a small area and included loss of some species and pathological problems in sea urchins (Clark et al., 1975). Other small spills have occurred in the area, primarily in maritime harbors, but their effects have not been studied. Existing levels of petroleum hydrocarbons in the study area were found to be very low at sites distant from harbors and refineries (Brown et al., 1979).

Spills of other hazardous substances have not been documented in the study area. However, a major PCB (polychlorinated biphenyl) spill occurred in the Duwamish River in Seattle south of the study area in 1974. Approximately 1,300 kg of Aroclor 1242, a PCB mixture, were spilled when a transformer was dropped. Some of the material was removed by dredging, but up to 2 ppm in sediments were recorded in the immediate area following the spill (Pavlou and Hom, 1979; Pavlou et al., 1977).

VI. A. 2. Oil refineries and transshipment facilities. Four oil refineries are located within the study area. Their total refining capacity is about 336,500 barrels per day. Despite the considerable efforts on the part of these industries to remove pollutants from wastewaters, chronic inputs of B.O.D. materials and oil and grease occur. A range of 10.2 to 29.5 mg/l B.O.D. and 3.7 to 11.9 mg/l oil and grease were measured in 1972 over a two-month period. Maximum pulses of 1,074 mg/l and 426 mg/l, respectively, were measured in 1974. Though the total oil removal efficiencies of the refinery wastewater treatment facilities ranged from 95 to 99.99%, these facilities were found to be relatively ineffective at removing soluble aromatic fractions (Pizzo et al., 1978). Consequently, petroleum hydrocarbon levels in sediments and mussel tissues collected near these refineries were often higher than in samples collected elsewhere in the study area (Brown et al., 1979).

No consistent indications of lethality among oyster larvae, and juvenile coho and chinook salmon exposed to undiluted refinery effluents and receiving water were recorded by the Washington Department of Fisheries (Pizzo et al., 1978). No studies on the effect of refinery operations on the benthos are available.

No crude oil or refined products pipelines traverse the study area at this time. Refinery products are currently transported to the Seattle area and other Northwest markets by truck, barge, overland pipeline, and ship. Puget Sound refineries shipped about 36 million barrels of products in 1974, 40% of which was transported by marine traffic (Pizzo et al., 1978).

Several proposed tanker-to-pipeline crude oil transportation facilities are under consideration for the area and/or nearby Canadian locations. If constructed, a throughput volume of 700,000 to 933,000 barrels per day would be expected in at least one of the proposed facilities, involving from 300 to 395 tanker port calls per year. Oil spills as a result of tanker collision or grounding and operational mistakes or equipment (e.g., pipeline) failure could occur (U.S. Bureau of Land Management, 1979). The processes that may determine the fate of oil spills resulting from the operation of one proposed facility and the biological communities that may be affected have been summarized (Long, 1980).

VI. A. 3. Habitat modification. The irreversible losses of habitat associated with dredging and construction of piers, marinas, jetties, bulkheads, etc. occur periodically in the study area. Loss of habitats can occur through removal of sediments, filling, burial, modification of nearshore currents, or removal of marsh or other vegetation.

The study area as a whole has been minimally impacted by projects that cause loss of habitat due, in part, to the low human population density. Those projects which have been implemented often were intended to either stabilize shorelines or protect and accommodate ships or boats. Habitat modifications which have occurred in the past include breakwater construction at Neah Bay; stabilization of Ediz Hook with rip-rap; construction of piers at Cherry Point, March Point, Dungeness and Port Angeles; construction of marinas at Sandy Point, Orcas Island, Friday Harbor, Port Angeles, Neah Bay, Birch Bay, Anacortes, and Bellingham; dredge-and-fill operatios at Semiahmoo Spit and Bellingham; and construction of structures and docks at Anacortes, Port Angeles, San Juan, Orcas, Shaw, and Lopez Islands.

VI. A. 4. Upland modification. Upland activities such as agriculture, construction, and logging ultimately affect marine habitats. Excessive nutrient inputs from fertilizer runoff, excessive suspended solids inputs from erosion and runoff of pesticides can reach the bays and estuaries of the study area and cause deleterious biological effects.

Upland modification activities are greatest along the Olympia Peninsula, in the Skagit River basin, and in areas surrounding Bellingham. Suspended solids loads from the Fraser River system to the north represent the single largest input to the study area. Stockner et al. (1979) observed trends in phytoplankton productivity and biomass apparently related to characteristics of the plume.

VI. A. 5. Forest products. Four major pulp mills are located in the study area (Bellingham, Anacortes, two in Port Angeles). Pollution problems from these mills have been documented and are of two types: First, the deposition of settleable solids in bays and harbors creates anaerobic conditions in the sediments and tends to eliminate many macrobenthos species. Second, the effluent, because of oxygen-demanding and toxic materials, can cause water quality problems. Lethal conditions to juvenile salmon, benthos (including oysters), and bivalve larvae have been documented (FWPCA, 1967).

Rafted logs are stored in water in a number of locations in the study area. Although no studies of the impact of log rafting are available for the study area, Waldichuk (1979) described some impacts in parts of British Columbia under conditions similar to those of the study area. Detrimental impacts of log rafting include compacting of sediments and smothering of benthos at intertidal log storage areas; production of organic leachate toxic to juvenile salmon; accumulation of oxygen-demanding bark and wood debris under log rafts, causing anaerobic conditions unsuitable for many benthic species including prey for juvenile salmon; and abrasion by shifting logs disrupting benthic fauna and rooted vegetation such as eelgrass.

VI. A. 6. Domestic wastes. Domestic wastes discharged from urban areas into marine waters, in most cases, only receive primary treatment. Although detrimental effects to the environment have not been documented in the study area, potential pollution effects from B.O.D. material, nutrients, and/or toxic substances (metals, organics) exist.

The largest metropolitan areas (Bellingham, Anacortes, Port Townsend, Friday Harbor, Port Angeles, Sequim) produce the greatest volumes of municipal sewage and, thus, potentially pose the greatest environmental problems. Permitted discharge volumes (millions of gallons per day) for the largest municipal waste treatment plants in the area were documented in 1975 as follows: Port Angeles, 2.3 mgd; Anacortes, 2.2 mgd; Bellingham, 1.56 mgd; Sequim, 0.57 mgd; Friday Harbor, 0.5 mgd. Smaller municipalities, such as Skyline (near Anacortes) and Ferndale, discharge considerably less than 500,000 gallons per day (National Commission on Water Quality, 1975).

VI. A. 7. Commercial and sports fisheries. Fisheries harvesting represents a major portion of the economy of the Pacific Northwest. Both anadromous and resident fish are caught along with shellfish. Gill nets, purse seines, trawls, and trolling gear are used to capture fish. Traps and pots are used to collect crab and shrimp. Both diver-operated and boat-operated hydraulic gear are used to collect subtidal bivalves, while rakes and shovels are used for intertidal bivalves.

Salmonid fishing activity within the study area is most intense in the Strait of Juan de Fuca, Rosario and Haro Straits, while bottomfish are collected most often in the embayments, such as Discovery Bay. Shrimp and crab are caught throughout the area and in the adjacent Hood Canal. Bivalve fisheries are restricted to the embayments, such as Dungeness and Discovery Bays.

The environmental implications of commercial harvesting of subtidal hardshell clams with a hydraulic escalator harvester have been observed in field experiments and summarized (WDOF/WDNR, 1978). Disturbance of the bottom results in furrows, redistribution of sediments, some burial of organisms, and temporarily increased suspended particle concentrations. Dislodged, nonharvested clams and other species may be vulnerable to predation. Some individuals may die due to shell breakage. The numbers of associated benthic species in areas affected by harvesters is reduced, but the abundance and biomass per unit area appear to remain unchanged. Marine eelgrass and algae beds can be lost due to removal; however, harvesters cannot operate in dense eelgrass mats. Thus far, very little of this activity occurs in the study area, but various parts of the Strait of Juan de Fuca support potentially harvestable clam beds.

VI. A. 8. Mariculture. Mariculture operations are largely restricted to salmonids and bivalves in the study area, often in suspended or floating pens or racks. The technology to raise marine algae is currently being develolped nearby, but is not yet operational. Salmonids have been raised in floating pens at one time or other at Lopez and Orcas Islands. Oyster raising operations have occurred in Dungeness Bay, Sequim Bay, Padilla Bay, Samish Bay, and Westcott Bay. Currently, plans for siting experimental algae mariculture apparatus focus upon embayments.

VI. A. 9. Recreation, educational activities, scientific collection. A wide variety of activities lumped together here can have detrimental biological effects, though usually unintentional. These activities are often greatest in biologically important areas as the biota are the attraction to many of the people causing the perturbation. Activities included here are: recreational boating near or among marine mammals and birds; recreational and commercial aviation near marine birds; beachcombing, walking, motorcycle riding, horseback riding, other recreational activities and dogs near or among nesting bird colonies; educational field trips; and collection and removal of organisms for educational and research purposes.

Areas where significant disturbance and/or removal of organisms has occurred include: Dungeness Spit; Protection Island; Smith Island; Sucia, Patos and Matia Islands; Tongue Point; Slip Point; Padilla Bay; and numerous bird nesting sites in the San Juan Islands.

Everitt et al. (1980) documented disturbance of harbor seals on Protection Island and Smith-Minor Islands. Groups of seals on Protection Island were disturbed (enough to flee to the adjacent water) most often by approaching boats and to a lesser degree by airplanes, beach walkers, and helicopters. Disturbance was greatest on weekends and usually at mid-day. The period of time involved for seals to return to haul-out sites following removal of the disturbance was not measured, but appeared to take from several hours to several days.

VI. B. General Perturbation Effects on Biological Communities

As described earlier in this report a wide variety of marine communities are found in this region. In the nonperturbed or "healthy" state, they vary greatly in the following community parameters: species components and organization, species richness and diversity, abundance, and biomass. No single measure would differentiate a healthy community from a possibly perturbed community. However, perturbations have general biological effects. An understanding of these plus careful study may allow assessment of perturbation impact at a given site.

Perturbations may be placed into three broad categories. The first is habitat alteration. Many perturbations involve a change in the physical characteristics at a site. For example, the construction of a breakwater may involve replacing a soft sediment habitat with a rock habitat. This results in the wholesale replacement of one community by another in response to destruction of one type of habitat and replacement by another. Community parameter measures would change to match those of the "new" community. There would be new species components and possibly organization. The parameters of species richness and diversity, abundance, and biomass may increase or decrease. Habitat alteration effects are generally dramatic and, given our general understanding of regional marine communities, the effects may be to some extent predictable.

A second category of the biological effects of perturbations is the nonselective destruction or enrichment of a community. Examples of nonselective destruction are often dramatic. An example is a crude oil spill. In the rocky intertidal the primary effect is suffocation of the entire community. Other toxicants may kill the entire community. Less acute nonselective pollutants may depress the community parameter measurements of species richness and diversity, abundance, and biomass compared to prestress values. Once the toxicant is removed, community values return in time to normal. Examples of nonselective enrichment are rare. In a hypothetical example, a slight nutrient addition might result in nonselective enrichment of an entire community where primary production is nutrient limited. Biological effects of nonselective perturbations may to some degree be predictable.

The perturbation category with the most complex and least predictable biological effects is a selective destruction or enrichment. Many or most perturbations affect community species members differently. Species specific responses are due to the differing physiological tolerances of organisms, differing feeding habits, microhabitats, life cycle sensitivity, or general life styles (sessile, motile, flyer, swimmer, etc.).

The community level result of species specific responses is potentially very complex and unpredictable. Community species components may change due to selective mortality of sensitive species or the addition of new opportunistic species resistant to the pollutant involved. Community organization may be altered. The species-rich marine communities are structured by complex interactions of predation and competition among its component species. Selective removal of a key predator or competitor may dramatically alter the community structure. Community food webs may also be dramatically altered by selective removal of a key predator or other vital trophic link. In general, selective perturbations reduce species richness and diversity. However, selective removal of a competitive dominant species may actually increase both richness and diversity.

Community productivity as reflected in the parameters of abundance and biomass may be increased or decreased by a pollutant. If the pollutant in nontoxic concentrations can serve as a nutrient substrate, blooms of the organisms able to utilize it may result in increased community productivity. However, most pollutants fall into the class of toxicants, which may decrease community productivity if key producers are sensitive.

From the discussion above it is apparent that the nature of the effect is highly dependent upon the nature of the cause. Some types of perturbations, for example, may cause an increase in productivity, possibly to the point where eutrophication occurs, while others may drastically reduce productivity. Some types may result in the total loss of a population, while another population may flourish. Some effects occurring over a short time can be easily observed and quantified. Other effects may be very subtle and are measurable only after considerable time.

VI. C. Perturbation Types and Their Possible Effects

Table 11 briefly outlines the major perturbation types in the study area as perceived by the authors; those communities and habitats most sensitive to each; the potential impacts of each and the biological processes affected; and environmental questions or concerns that should be examined to lessen or estimate possible effects. This table is not intended to be exhaustive but, rather, provides a framework for considering possible environmental repercussions of each type of perturbation.

VI. C. 1. Oil spills and other industrial accidents. Acute effects of spills of crude oil, petroleum products, or other toxic substances have historically been documented among marine birds and benthos. Adult fish and

Table 11. Major perturbation types and their possible effects in the study area

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
A. Oil Spills and Other Industrial Accidents - oil spills - hazardous substance spills	- birds - benthos - fish - mammals	- open water - protected intertidal habitats - protected bays	- direct mortality caused by toxic effects of hazardous substances - decrease in bird hatching success due to oiling of eggs - mortality, morbidity of benthos, causing community and biomass changes - retention of oil in protected muddy habitats, inhibiting recolonization - death of benthos larvae, leading to community changes - tainting of benthos, fish - increased mortality among pinniped pups; increased chances of mother/pup separation; disturbance during spill cleanup operations	- changes in population sizes due to emigration, mortalities, decreased hatching success - changes in community composition and biomass leads to changes in food webs and productivity - decrease in population size, growth rate, spatfall success in commercial bivalves - tainting decreases marketability of seafoods	- What method and plans are available to protect biologically important areas? - Which areas, habitats and seasons are especially sensitive? - What recovery rates are to be expected? - How will food webs be affected by loss of prey groups? - What economic impacts are expected? - What preventative measures can be implemented to decrease spills? - Are species of critical trophic importance also those most sensitive to effects of oil?

Continued

Table II (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
B. Petroleum Refining, Transshipment and Utilization					
- chronic oil inputs in refinery wastewater - atmospheric inputs from refinery stack emissions - oil inputs from bilges, small dockside spills, marinas, small craft, etc.	- benthos - fish - seabirds (especially diving species)	- bays - protected intertidal and nearshore habitats	- chronic inputs of hydrocarbons cause mortalities and abnormalities among larvae of benthos and fish - chronic inputs of hydrocarbons lead to physiologic stresses, histopathologic diseases and behavioral changes in adult benthos and fish - seabirds susceptible to oil-fouling and death during small spills	- changes in benthos and fish community composition - decrease in reproductive success among benthos and fish - histopathologic diseases cause decreased ability to compete for food, to avoid predators, and to reproduce - losses of seabirds leads to community composition changes and decreased density	- Will decreasing or stopping chronic hydrocarbon inputs minimize or eliminate impacts? - Are there siting alternatives that would avoid impacts upon important biologic communities or result in rapid and considerable dilution of inputs? - Can effluent/emission be used to reduce monitoring data effects? - Can safeguards (e.g., booms) or regulatory actions be implemented to decrease impacts?

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
C. Habitat Modifications - piers, jetties, marinas, bulkheads - solid and wood waste fills - dredging (shellfish and channelization) and filling - buildings, underwater pipelines, bridges, other structures	- infaunal zoobenthos - shore and diving birds - marine mammals - fish (e.g., spawning herring)	- all	- removal, loss, burial or substitution of habitat/substratum types, causing changes in community composition - changes in nearshore circulation, possibly leading to beach morphology changes and further burial or habitat loss, shifts in sediment characteristics and changes in replenishment of nearshore water masses - disturbance of birds and mammals during construction - burial or removal of biota, nests, eggs, animal burrows, causing direct mortality - removal or modification of roosting, resting, haul-out site habitats	- alteration of water quality and current patterns - decrease in availability of food species - decrease in plant productivity due to removal or loss of suitable substratum - shift in faunal community structure to less desirable state - decreased hatching, nesting, pupping success - decreased benthic biomass - emigration of seals and birds, decreasing population size	- Can the proposed project be modified to decrease habitat loss? - Can construction be scheduled for a season in which disturbance would be minimal? - Can new habitats be established to replace that which will be lost? - Will any new habitats be suitable for biota? - Are there siting alternatives that would minimize impacts? - What is the estimated recolonization period and is enhancement (e.g., bivalve seeding) feasible?

Potential Impacts (contd.)
- possible rerelease of sediment-bound toxic chemicals

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
D. Upland Modification - agriculture - logging - inputs via rivers and streams of pesticides and suspended solids	- phyto- and zooplankton - benthos - fish larvae	- estuaries/ bays	- excessive inputs of nutrients, possibly leading to eutrophication - inputs of pesticides and uptake by marine biota - excessive suspended solids runoff leading to turbidity and siltation in estuaries and bays	- eutrophication could cause anoxia and change in plankton (including fish larvae) and benthos community composition - uptake of pesticides could cause death or histopathological diseases, especially among crustaceans, and subsequent biomagnification among predators - turbidity can decrease light penetration and impair the function of plants and phytoplankton - suspended particles can impair physiologic process of zooplankton and fish larvae, leading to increased mortality. - siltation can smother benthic communities and alter substratum type	- What is the capacity of bays/estuaries for assimilating pollutants resulting from upland modification? - What pesticides will be used? What conconcentrations will likely result? And are any effects likely to occur at those concentrations? - What measures can be taken to minimize pollutant loads? - What are the seasonal relationships of potential effects and pollutant input rates?

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
E. Forest Products - pulp and paper mill effluents - log-rafting - chips, debris	- zoobenthos - fish larvae - zoobenthos larvae	- bays/ estuaries	- mill wastewater discharges, causing direct mortality among larval forms of fish and benthos - lignins, tanins, chips and debris leached or spilled into water, causing death or burial of benthos and modification of substratum characteristics - logs directly scour or abrade bottom, removing or crushing benthos	- decrease in benthos and fish population sizes through death of larvae, modification of bottom substrata - decrease in benthos biomass through toxic effects of effluents, leachates, scouring, or abrasion - low-oxygen or anoxic conditions in near-bottom water caused by B.O.D. materials, leading to physiologic stresses	- Can potential impacts be minimized by siting alternatives if new mills or other facilities are built? - Can potential impacts be minimized by modifying practices and implementing seasonal controls? - Can log-rafting methods be modified to minimize or eliminate impacts?

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directed Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
F. Domestic Wastes - municipal wastes (sewage) - urban runoff - nonpoint sources	- phyto- and zooplankton - benthos - fish larvae	- poorly flushed bays	- nutrient inputs raised, leading to eutrophication - excessive inputs of freshwater, suspended solids may cause mortalities due to changes in water chemistry - inputs of toxic substances may be taken up by biota - inputs of pathogenic bacteria and/or toxic substances may contaminate seafood	- eutrophication can lead to anoxia, lethal to plankton, benthos - productivity depressed and composition of plankton communities changed - subtle histopathologic diseases caused by toxic substances - physiological processes altered or stressed, e.g., osmoregulation - food webs and other species-species relationships altered; some predators may leave due to lack of suitable prey - loss of or decrease in harvestable fisheries	- Are there siting alternatives that would eliminate or minimize anoxia conditions? - Will eliminating or diminishing pollutant inputs alleviate physiologic stresses? - Will eliminating or decreasing toxics and bacterial inputs alleviate human health problems? - What are the ecologic repercussions of altering food webs? - Are there alternatives to waste water discharge? - How can effects of discharges be monitored? - What is the carrying capacity of receiving waters to accommodate pollutant inputs?

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitat	Potential Impacts	Processes Affected	Environmental Questions
G. Commercial and Sports Fisheries - finfish - shellfish	- fish - diving birds - marine mammals - subtidal zoobenthos	- open straits - nearshore (all)	- excessive selective removal of target species - incidental drowning of diving birds, seals; incidental removal of nontarget species - loss or disruption of sediments by shellfish-gathering machinery - disturbance of marine birds, mammals - significant removal of important prey resources	- selective removal of predators, affecting food webs, predator pressure and overall community structure - decrease in standing stock of target species, species accidentally killed and predators - decrease in benthos species richness and standing stock due to removal or loss of substratum - emigration of species intolerant of disturbance, affecting density and community composition	- Can fishery be implemented so as to decrease or eliminate incidental deaths? - Can fishing pressure be timed or regulated to minimize effects of loss of target species? - What is expected recovery time of incidentally affected communities if fishery were stopped? - What is maximum fishing pressure target species and nontarget species can tolerate? - Are there shellfish harvesting techniques which minimize sediment disturbance?

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitat	Potential Impacts	Processes Affected	Environmental Questions
H. Mariculture - shellfish - finfish pens	- benthos - certain marine birds	- protected bays	- fecal wastes cause substratum modification, increases in B.O.D., burial and smothering of adjacent or underlying benthos, increases in sedimentation rates - pens, floats, other equipment attract some bird species and disturb others - production or utilization (depending on type of operation) of nutrients may lead to nutrient level changes in water	-increased oxygen demand near sediment-water interface can cause community composition, biomass changes among benthos - changes in marine bird communities can occur due to emigration of some species and immigration of others, possibly including nuisance species - plankton communities may change due to nutrient level changes	- Are siting alternatives or pen rotation schemes available to decrease potential impacts? - Can benthos community changes, if any, be monitored? - What means are there to minimize disturbance of marine birds? - What is the physical/chemical fate of fecal wastes? - What is the assimilative capacity of of the local ecosystem relative to the magnitude of the facility? - What are the biological effects of predator control practices? - What means are available to avoid attracting predator?

Continued

Table 11 (Contd.)

Perturbation Types	Especially Sensitive Communities Directly Affected	Especially Sensitive Habitats	Potential Impacts	Processes Affected	Environmental Questions
I. Recreation, Educational Activities, Scientific Collection - boating - aviation - beachcombing - educational field trips	- epibenthos - marine birds - marine mammals	- rock and cobble (especially with tide-pools) - protected embayments - isolated rocks, islets, sand spits	- selective removal, trampling, and mortality of rock/cobble community species - disruption or disturbance of nesting, hatching, pupping or rearing activities	- changes in benthos community structure and density - decrease in bird and mammal population size due to emigration and impaired reproductive success - decrease in predator pressure, possibly leading to prey community changes	- Can recreation and educational activities be conducted without causing biologic impacts? - Can these activities be regulated or restricted to avoid nesting or other sensitive seasons? - Is disturbance a transient effect? How long does recovery take? - Should especially sensitive areas be set aside for complete exclusion of humans?

mammals are largely able to avoid oil spills, though losses of fish and seal pups have been documented during oil spills. Fish eggs, larvae, and juveniles are more susceptible to the effects of oil spills than adults. Marine organisms may not escape toxic substances as easily if the substances become dissolved. Mortality among the plankton undoubtedly occurs during spills, but it is very difficult to measure. Also, plankton communities have the capacity to recover very quickly.

Open water habitats (e.g., western Strait of Juan de Fuca) where huge numbers of marine birds feed and roost would be especially sensitive. Protected mudflats, eelgrass beds, and bays (e.g., Dungeness Bay, Jamestown, Padilla Bay) would also be sensitive because of the density of marine birds and benthos in those habitats and the possible long-term effects of spilled substances there. Spilled substances such as crude oil would become trapped in protected habitats and little physical energy would be available to facilitate the weathering and/or transport out of the area.

Spilled substances could cause direct mortality to birds coming in contact with the substance; mortality to benthos due to smothering or toxicity; loss of larvae, chicks, juveniles, or other offspring due to toxicity; inhibition of benthos recruitment due to loss of larvae or unsuitability of the substrate; and tainting of marine biota used as food by predators and man. These impacts could, in turn, lead to decreased bird populations; changes in benthos community composition, productivity and biomass; changes in food web structures; decreases in commercial bivalve stocks; and decreased (temporarily) marketability of seafood species.

VI. C. 2. Petroleum refining, transshipment and utilization. Chronic effects of low-level inputs of petroleum hydrocarbons from refineries, transshipment facilities, and spills and leaks from a wide variety of other sources can occur among the benthos, fish, and birds. The magnitude of effects would be greatest in habitats where dilution, through weathering and/or transport, would be minimal, i.e., in protected bays, mudflats, eelgrass beds, and marshes (e.g., Padilla and Dungeness Bays).

Low-level inputs of petroleum hydrocarbons would have little biological impact if the resulting environmental loads were small. That is, if inputs were dilute, small in volume, or rapidly dispersed, impacts may be minimal. However, if repeated or continual inputs occurred and dilution was minimal, sublethal effects may occur as well as death among some species.

The larval and other young stages of benthos and fish are especially sensitive to low levels of petroleum hydrocarbons. Depending upon the hydrocarbon concentration, death or a variety of behavioral, physiological, or histological changes may occur among the adults or young. Seabirds (especially diving species) may be lost due to direct toxicity and oil-fouling in highly-concentrated oil slicks. These impacts could, in turn, lead to changes in community composition, standing stock, and density of benthos and fish; decreased reproductive success; decreased abilities to compete for food, space, mates, and to avoid predators and disease; and altered seabird communities. Marine mammals may be affected by disturbance during cleanup operations.

VI. C. 3. Habitat modifications. A wide variety of activities in the marine environment result in removal, modification, or substitution of the habitat(s) that certain organisms depend upon. Since these activities are mostly restricted to nearshore and shoreline areas, the habitats therein are most often affected.

Infaunal benthic animals are highly sensitive to burial and removal or substitution of substrate. Many have limited vertical burrowing capabilities if buried, all are removed if the substrate they are associated with is removed, and all have low tolerance of substrate substitution. Pacific herring and other organisms spawn among eelgrass or other vegetation and, therefore, are sensitive to removal of either the vegetation itself or the substrate they reside in. Marine birds and mammals are sensitive to disturbance, loss of feeding habitat (e.g., Black Brant and eelgrass) and loss of nesting, roosting, or hauling-out sites.

Impacts commonly associated with habitat loss include: changes in community composition and/or wholesale loss of benthos; changes in nearshore or littoral circulation as a result of changes in beach morphology; disturbance and emigration of birds and mammals; burial or removal of biota or their nests, eggs, or burrows; removal or modification of habitats at roosting, resting, and haul-out sites; and possible release of sediment-bound toxicants. These impacts could, in turn, result in decreased biomass, density, and productivity of benthos; changed benthic community composition and prey availability; decreased bird and mammal populations and reproductive rates; and alterations in current patterns and water quality.

Habitat modification may be mitigated, in part, by creation of new habitats (e.g., floats, pilings, rip-rap) for marine organisms. However, species assemblages may differ considerably from those of the original substrate type.

VI. C. 4. Upland modification. Upland construction activities and other actions that affect soil management can have both discrete and subtle effects on marine biota many kilometers away. These effects invariably involve an intermediary stream; thus, they are most likely to affect an estuary receiving such a stream. The plankton, benthos, and fish larvae living in estuaries and bays are most sensitive.

Potential impacts are induced by excessive runoff of nutrients, suspended solids, and/or pesticides, and subsequent transport of these materials to the marine system via streams. Excessive nutrient inputs can cause rapid plankton blooms and eutrophication, possibly leading to an anoxic condition that affects all biota. Inputs of pesticides can cause death or sublethal effects among the plankton, benthos, and mammals. Since most pesticides are very long-lived, they can be transmitted from prey to predator causing excessive levels in the tissues of birds and mammals, leading, at high levels, to decreased ability to survive and reproduce. Inputs of suspended particles can decrease primary productivity due to shading of plants; can clog feeding and respiratory organs of plankton, benthic invertebrates, and fish; and can bury or smother benthic organisms.

Generally, the repercussions of these impacts include decreased biomass, productivity, density, and diversity of biological communities. Impacts resulting from pesticide inputs could be long-term due to the stability of pesticide compounds, whereas those of nutrient or suspended solid inputs would stop shortly after the sources were cut off.

VI. C. 5. Forest products. A wide variety of environmental problems associated with the forest products industry, besides those attributed to logging operations, have been documented. Pulp and paper mill effluents are lethal to many organisms, especially the larvae of some zoobenthos and fish. The toxicity of many effluents has decreased in recent years, however, due to implementation of effluent treatment practices. Log-rafting results in the release of toxic lignins and tanins into the water. Mill effluents and log leachates cause greatest problems in confined areas where dilution is minimal; thus, bays and estuaries with poor water exchange are most sensitive. Also, the young of many species of fish and bivalves are reared in bays and estuaries.

Log-rafting can also cause severe scouring or abrasion of surrounding or underlying benthos (discussed above) as the rafts shift back and forth in response to he tides, winds, currents, and handling. Chips and debris resulting from sawmill operations and log-rafting often sink and can smother the underlying benthos, cause anoxia during decomposition, and release lignins and tanins.

The repercussions of these impacts can, in turn, include decreased density of benthos and fish populations, including totally abiotic sediments; decreased benthos biomass; and water quality-related physiologic stresses and mortality. In the case of mill effluents and log leachates, recovery would be expected to be relatively quick following a cutoff of the source(s), assuming toxic materials had not accumulated appreciably on the bottom. Recovery of benthos in areas impacted with chips and debris would be relatively slow, since suitable substrate and near-bottom water quality conditions would not be available until the chips and debris were either removed or decomposed.

VI. C. 6. Domestic wastes. Municipal sewage, urban (street) runoff, septic drain fields, and nonpoint source wastes involve environmental problems as a result of excessive nurtrients, suspended solids, freshwater, toxic substances, and pathogenic bacteria inputs. These problems are related to magnitude and concentration; thus, poorly flushed bays or other relatively confined areas with poor exchange are likely to be the most sensitive.

Nutrient inputs can cause rapid plankton blooms which can lead to eutrophication and anoxia. Low oxygen levels would affect all biota. Depressed salinity and increased suspended solids can lead to death, decreased primary productivity, and emigration of sensitive species among the plankton, benthos, and fish. Both factors can also cause alterations of certain physiologic processes, such as osmoregulation and respiration. Toxic substances such as metals, aromatics, and chlorinated hydrocarbons can cause a wide variety of concentration-dependent problems, including death, pathologic diseases, behavioral changes, and interruption of physiologic processes among plankton, benthos, and fish. Pathogenic bacteria and toxic substances may make certain seafoods unmarketable.

The results of these impacts may include: changes in density, biomass, and community composition of plankton, benthos, and fish; decreased primary productivity; long-term subtle physiologic, behavioral, and pathologic effects, possibly causing decreased ability to compete for available resources and to reproduce; altered food webs; and loss of revenue from contaminated seafoods. Nutrient inputs from domestic effluents may serve as a boon to overall productivity in nutrient-limited systems; but community changes due to competitive exclusion and toxicity of toxic substances may also occur.

VI. C. 7. Commercial and sports fisheries. To many people these activities may not seem to constitute a perturbation. Usually a thriving fishery is indicative of good water quality and a healthy ecosystem. However, a variety of stresses are indeed imposed upon some biota as a result of these activities, not the least of which is excessive selective removal of the target species. The sensitive biota (Table 11) are those which are sought and those incidentally killed or injured. The sensitive habitats are those in which the fishery is usually harvested.

The biological effects of fisheries activities vary greatly with the type of gear used and the target species. The most obvious impact is selective removal of large numbers of the target species, a decrease in density that otherwise would not occur. Direct effects often occur to predators, many of which are target species of commercial fisheries. If the target species is an important prey species, as in the case of herring and shrimp, prey resources for predators would be decreased. Another impact is death or injury of incidentally-caught nontarget fish and shellfish and entanglement and drowning of diving birds and marine mammals. Entanglement and drowning of some birds, such as Western Grebes, may increase if all fishery seasons are extended into winter. Loss or disruption of bottom sediments and epifauna by dragging (trawling) and hydraulic equipment can occur. Hydraulic and hand equipment for digging in the bottom disrupts sediments, especially in shallow muddy habitats. Disturbance of marine birds and mammals by passing boats and equipment can cause these animals to flee.

Removal of prey and/or predator species can result in changes in prey-predator relationships, food web structures, community changes, and decreased standing stock of target and nontarget species. Decreased benthos species richness would result from disturbance or removal of substrate. Emigration of species sensitive to disturbance would occur if the disturbance was continuous or repeated often, though many may return quickly after the disturbance is discontinued.

VI. C. 8. Mariculture. This is a relative new industry in the Puget Sound area and little is known of the effects of mariculture operations upon the surrounding environment. However, at least three problem areas are apparent: fecal waste inputs from the population being cultured, attraction of some birds and disturbance of others, and alteration of nutrient levels.

Fecal waste inputs, which could be sizable and poorly dispersed in protected bays or inlets, could be expected to impact nearby, or, in the case of suspended or floating racks or pens, underlying benthos. Modification of the substrate, increased B.O.D., burial, and smothering of organisms due to sedimentation of feces and excess food may occur. The operational equipment may attract some birds, especially fish-eating species, gulls and crows, and disturb others. Decomposition of animal wastes and excess food may increase nutrient levels, while photosynthesis of cultured algae populations may strip the surrounding water of nutrients.

Overall, changes in benthos, bird, and plankton communities may be expected. In a worst-case situation, bottom sediments may become abiotic directly underneath a floating or suspended animal culturing operation.

VI. C. 9. Recreation, educational activities, scientific collection. As with fisheries (above) these activities are not often considered to be harmful to the marine environment. In most cases they are not. But when performed often, or by many people, they can cause severe problems, including death or disturbance of biota.

Two widely differing impacts are possible. The first, removal, trampling and death of epibenthos, is often restricted to rock and cobble habitats. These impacts result from vandalism, running or walking on rocks, and recreational or scientific collection of intertidal biota. Collection of intertidal biota is restricted in those areas designated as marine preserves.

The second, disturbance, occurs as a result of boating and aviation in areas, especially bays, where marine birds congregate; boating in areas near where marine mammals haul out (e.g., isolated rocks, islets, and sand spits); and beachcombing, horseback riding, motorcycle riding, etc. on beaches where nesting, roosting, pupping, or rearing activities of birds and mammals occur. Unintentional disturbance of bird nesting colonies has been known to result in crows taking eggs from unattended nests. Scuba diving and snorkeling near colonies, roosts, and haul-out sites, along with sport fishing from boats in adjacent kelp beds, may keep birds off nests and under stress for extended periods. As a result, chilled eggs, young stressed by heat or cold, or predation on eggs or young may occur. Disturbance of foraging cetaceans by recreational boaters can potentially disrupt feeding patterns or interfere with mother/calf relationships.

Changes in epibenthos community structure would occur in areas severely or repeatedly impacted. Decreased bird and mammal population sizes would occur if adults emigrated to other areas or reproductive success was impaired. Also if these population sizes decreased, prey communities may change due to lack of predator pressure.

VI. C. 10. Miscellaneous. Biological impacts could potentially arise from other human activities in the area. These impacts would vary in magnitude and type according to the activity.

Atmospheric fallout of radioisotopes, fly ash, soot, or acid rain are possible, especially from major industrial activities within or adjacent to the study area. Acid rain is known to cause pH problems in the northeastern United States lakes that lead to diminished fish populations there. Atmospheric fallout is not controllable, though source emissions are.

Maritime traffic (nonspill related) can cause bird and mammal disturbance in open water and the habitat modification problems described above can result from the construction of port facilities. Oiling of birds by bilge wastes can occur.

Dissolved and particulate aluminum refinery effluents may decrease receiving-water quality and smother benthos adjacent to the plants. Overall, biological effects may be difficult to measure. Power plant effluents may affect the receiving-water by increasing water temperature, killing plankton and fish due to entrainment and impingement and inputs of biocides such as chlorine. Changes in community structure and density, reproductive success, metabolic rates, and feeding activity may occur.

Toxic chemicals such as metals, petroleum hydrocarbons, and synthetic chlorinated hydrocarbons may cause biological impacts. These chemicals can reach the biota either through historical or on-going inputs. They can cause a wide variety of histopathological diseases, similar to those found nearby in the waterways near Seattle and Tacoma; changes in benthos communities; death among plankton and bivalve larvae; and decreased reproductive success among birds. Elevated levels of toxic chemicals have been found in sediments collected in Bellingham Bay, Port Angeles harbor, and southern Strait of Georgia.

Although no large urban areas exist in the study area, the potential exists for low level chronic stress on water quality there by influxes of pollutants from adjacent areas. Transport of pollutants from the Fraser River/southern Strait of Georgia system and from the main basin of Puget Sound pose the greatest potential threats. Mixing of water masses carrying chlorinated organics, petroleum hydrocarbons, and trace metals is possible.

VI. D. Potential for cumulative and long-term subtle effects

The perturbation types and associated effects discussed above do not occur singly or in a vacuum. Antagonistic or synergistic effects can occur where two or more perturbations have opposite or additive influences, respectively. In the case of oil spills, an antagonistic perturbation may be a high-nutrient, high-temperature effluent that results in increased microbial decomposition of the spilled oil in an area where decomposition normally is limited by nutrients and temperature. Oil spills may cause greater effects in areas receiving continual low-level hydrocarbon discharges than in areas without these additional inputs.

Biological stresses such as molting, along with physical factors such as weather or freezing, can create synergistic situations among biological communities. Cumulative effects may result from repeated stresses that, individually, have little or no effect.

Visibly dramatic effects, such as a massive fish or bird mortality, from acutely toxic perturbations, usually are ephemeral in nature. Biologic systems have evolved to quickly mediate such short-lived insults, even though they may be extensive in scope. Rapid dispersal, dilution, and biodegradation of toxicants; recruitment and recolonization by organisms from adjacent, healthy habitats; and increased population growth of residual organisms will act to facilitate the recovery of the endemic community. Sublethal or chronic perturbations which persistently impact a habitat, on the other hand, have the potential to cause significant changes in the structure and productivity of the community. The fact that these subtle insults usually go undetected or take a long time to manifest themselves as an identifiable problem, attributable to a known perturbation, implies that the long-term effects are potentially the more deleterious and the recovery of the community more prolonged. Chronic perturbations in the form of pollutants can be the result of either continuous introductions of low-level concentrations or the entrapment of a large concentration of pollutant and subsequent leeching of toxic components from that source.

The potential mechanisms of damage to the community are diverse and their effects vary according to habitat type (Malins, 1977; Simenstad et al., 1979). The productivity of the community can be depressed through direct alteration of growth, metabolism, and reproduction of either producer or consumer organisms and indirectly through the removal of habitat. The latter affects primary producers the most, where the reduction of nutrients, light, or the availability of substrate (in the case of attached plants) can reduce the amount or rate of carbon fixed. Communities in all habitats are vulnerable to such effects but those of contained embayments, where restricted water circulation and fine sediments tend to accumulate pollutants, would appear to be particularly susceptible. Phytoplankton productivity in the bays and associated with water over nearshore mud, nearshore mud-sand, and nearshore mud-gravel habitats and the production of eelgrass in the intertidal/subtidal mud, mud-sand, and mud-gravel habitats would be most susceptible to sublethal disruption of water-borne pollutants (especially oil), as would the associated neritic and epibenthic zooplankton communities in these habitats.

Changes in food resources, although often involving only qualitative shifts in community structure, can result in subsequent changes in populations of consumer organisms. In general, most consumers are adapted to exploit a restricted portion of the prey community available to them, thus minimizing the deleterious effects of competition with other organisms and their vulnerability to predation. Selective reduction of the principal prey of dominant consumer organisms will thus force the consumers to switch to "less than optimum" prey and, at a minimum, result in lower total production or, at an extreme, cause the exclusion of the species. Neritic and epibenthic zooplankton-eating fishes, especially larvae and juveniles, would appear to be extremely sensitive to such a perturbation. These fishes include juvenile Pacific salmon, herring, and sand lance in nearshore and offshore habitats. And, consequently, the production of young by Rhinoceros Auklets, which feed extensively upon these fishes in those habitats adjacent to Protection Island during nesting season, may also be limited by their dependence upon this unique food resource.

Selective effects upon particular components of the community may be even more far-reaching, as in the case of keystone species. These dominants, by their selective predation on competitively dominant species at lower trophic levels or by their own competitive dominance, fill key roles in structuring the character of the nearshore community. Significant reduction of such species or inhibition of their predator or competitor functions will likely drive the community toward a new, different structure which, in itself, may become ecologically stable. Two habitats would be most susceptible to such an alteration. The subtidal rock habitat supports several predacious starfish (*Pisaster ochraceus*, *Leptasterias hexactis*, *Pycnopodia helianthoides*) and herbivorous sea urchins (*Strongylocentrotus* spp.) which constitute keystone species in their maintenance of the community structure as we know it. Most of these species (at least the nonbrooding species) are also known to have very intermittent and often low recruitment such that significant reduction in their abundance or in their reproductive potential would probably result in a sustained modification of the nearshore community structure for years or decades. If an impact occurs to the starfish only, the sea urchin population may proliferate. Then the production of macrophytic algae could be reduced dramatically by increased grazing. Also, a probable secondary consequence may include reduced detritus input to food webs in the region. In the intertidal/subtidal mud and mud-gravel habitats predatory gastropods and large infaunal bivalves play similar roles and, coincidentally, also have low rates of recruitment.

The actual physiological and pathological condition of individual organisms can also be directly affected by perturbations involving a subtle decrease in water quality. Increased vulnerability to histopathological diseases, if not resulting in direct mortality, can increase the susceptibility of the diseased organism to predation or reduce their competitive advantage such that the population can be measurably affected. Some pollutants have been implicated as mutagenic agents and, as such, could be responsible for adverse changes in physiological or morphological characteristics of future generations or ovigerous organisms influenced by the pollutant. Agents which have been implicated in these effects include chlorinated hydrocarbons (pesticides), heavy metals, polychlorinated biphenyls, and aromatic hydrocarbons. Sensitive habitats have included soft-sediment subtidal regions adjacent to heavy industrial and agricultural runoff. In the case of the northern Puget Sound-Strait of Juan de Fuca region, epibenthic and benthic communities of subtidal protected mud habitats are the most likely to face such an insult, especially those associated with contained embayments with low flushing and turnover rates of the water mass within. Harbors and marinas would be additionally sensitive.

In examining the overall susceptibility of the various habitats in the region to extended sublethal effects, it is apparent that the soft sediment habitats are the most vulnerable. They have a tendency to entrain pollutants within the sediments, often preserving their toxic effects until they are released at a later date. They can be released either physically (through erosion) or biologically (via burrowing infauna) and thus made available to incorporation into the food web. The fact that these habitats tend to be the most productive in the region and are almost completely based upon the decomposition of detritus makes them even more susceptible to alteration. As mentioned previously, the sorption of pollutants upon detrital particles may constitute one of the most important pathways by which a pollutant may be transported through food web linkages, potentially causing subtle but long-term effects upon the organisms at each trophic level.

VII. DATA EVALUATION, DATA GAPS, RECOMMENDATIONS

VII. A. Evaluation of the MESA/WDOE Data Set

In compiling this synthesis, we have probably tended to overemphasize the data gaps and unanswered questions resulting from our interpretation of the voluminous baseline study data. This tendency, however, is the logical result of both scientific hindsight and the problem of addressing *a posteriori* questions about ecological processes based upon a purely descriptive data base. We believe the basic knowledge gathered during these two studies is important, for we would not be in the position of projecting the various processes and impacts discussed above in Chapters V and VI if we had only the meager, fragmented data on nearshore communities which existed prior to 1974.

The list of advances achieved during the biological studies is too lengthy to enumerate in full, but the major accomplishments unique to the state of the science in this region should be noted:

1. The first systematic documentation of community (taxonomic) structure, density, and standing crop in representative (parallel) intertidal/subtidal and nearshore habitats for a broad spectrum of the communities, from macroalgae to marine mammals;

2. Characterization of plankton, birds, and mammals in offshore (deep) waters;

3. Quantitative documentation of seasonal and annual variations in species abundance and community parameters;

4. A synthesis of trophic structure and prey-predator interactions among the major organisms on a habitat basis;

5. Distributional and taxonomic clarification or extension of many groups, especially the crustaceans;

6. Baseline levels of petroleum hydrocarbons that organisms in the nearshore habitats are now exposed to relative to existing (potential) sources of chronic release and to locations beyond the influence of any known sources;

7. The first controlled oil spill experiments on in situ intertidal/shallow subtidal communities in the region and quantitative documentation of the community response and recovery rates;

8. Synthesis of available data collected on biota of the region;

9. The processes and controlling factors of oil degradation by microorganisms;

10. Identification of relationships between the physical processes that could disperse and transport oil spills and the important biological populations and communities that may be adversely affected;

11. Statistical analyses of baseline data and estimates, based upon the results of these analyses, of the utility of the data in predicting or assessing damage caused by a major perturbation such as an oil spill;

12. Development of a shoreline oil-sensitivity index for habitats of the region and mapping of the extent of these habitats.

Additional work involving oceanographic processes are summarized in Cannon (1978) and Holbrook et al. (1980).

While some elements of the biological research had been described for northern Puget Sound, especially in the region of the University of Washington's Friday Harbor Laboratories on San Juan Island, essentially nothing was known about the nearshore or offshore communities and habitats along most of the Strait of Juan de Fuca. This was completely virgin territory for the intertidal ecologist as well as the fisheries biologist and marine mammalogist.

VII. B. Data Gaps

Despite the extensive regional data base developed in the past five or six years and described above, both topical and geographic data gaps exist. Only the macrobenthos ($>$1 mm) were sampled, except in the case of epibenthic zooplankton. No quantitative data exists for the meio- or microfauna or the microflora. Very little quantitative data exist for deep offshore benthos, so it was omitted entirely in this repott. Except for the one-time collection of epibenthic zooplankton, no nearshore or intertidal/shallow subtidal plankton (including ichthyoplankton) data have been collected. No quantitative offshore fish sampling was done. Offshore fish information given in this report is, therefore, largely qualitative. No research was performed expressly to learn the ecological relationships of most communities; population counts were emphasized. Marine mammal studies emphasized easily observed pinniped populations; abundance and distribution of cetaceans were poorly documented. No data were collected for the saltmarsh habitat. Little work was done on subtidal rocky-reef kelp bed fishes.

Perhaps the most significant topical data gap is production or rate information. Studies in the region on benthic primary production, general secondary and tertiary production, and bacterial and fungal degradation are almost totally lacking. The data accumulated to date addresses only standing stock, not the rate of energy flow through the biological system.

Geographic gaps were implied in the introduction. The boundaries of this report were artificial and did not necessarily follow the natural boundaries of any system. The northern boundary of the study was the Canadian border, not the natural northern boundary of this system. Little work was performed in the southern Strait of Georgia, particularly in the Canadian portions. The western boundary was Cape Flattery, thus omitting the outer coast. The west side of Whidbey Island was part of the eastern boundary thus leaving out the Saratoga Passage/Skagit Bay area. The southern boundary was Admiralty Inlet omitting all of Puget Sound proper and Hood Canal. Relatively few intertidal benthos and nearshore fish data were collected in the interior of the San Juan Islands compared to other regions within the study area.

VII. C. Recommendations for Further Research

Data needed to more fully understand the biology of the area include:

- productivity estimates and population characteristics of dominant species;
- statistically-derived sampling designs for benthos;
- distribution and abundance of those biota not yet surveyed - cetaceans, nearshore plankton, rocky-reef fishes, meiofauna;
- comprehensive survey data for nearby areas not yet studied - Puget Sound, Hood Canal, areas east of Whidbey Island, outer coast, adjacent Canadian waters;
- energetics of intertidal/subtidal communities and relative roles of phytoplankton, attached plants, and benthic diatoms in productivity;
- relative importance of intertidal/subtidal habitats in reproduction and rearing of young animals;
- recruitment dynamics of intertidal communities;
- functional relationships between prey and predators;
- systematic monitoring of benthos, marine mammals, and birds at selected protected areas;
- reliability of and variability in marine bird and mammal census data;
- quantification of prey uptake by marine birds, fish, and mammals;
- rates of interactions of birds and mammals with fisheries;
- further definition of the relative abundance of epibenthic zooplankton at major habitat types;

- method for rapidly assessing harbor seal populations in the event of an oil spill; and
- relative importance of roosting/nesting sites and hauling-out sites for birds and mammals, respectively, and movements of animals to and from these sites.

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Simenstad, C. A., B. S. Miller, J. N. Cross, K. L. Fresh, S. N. Steinfort, and J. C. Fegley. 1977. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of nearshore fish. NOAA Tech. Memo. ERL MESA-20, MESA Prog., Environ. Res. Lab., Boulder, Colo. 144 pp.

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Webber, H. H. 1980. Whidbey Island intertidal and shallow subtidal benthos. U.S. Dept. Comm./EPA Interagency Energy/Environment R&D Program Report EPA-600/7-80-167. 91 pp.

Webber, H. H. 1981. Growth rates of benthic algae and invertebrates in Puget Sound. I. Literature Review, and II. Field studies on Laminaria hereocystis NOAA Tech. Memo OMPA-4, Office of Marine Pollution Assessment, Boulder, Colo. 45 pp.

Wiens, J. A., D. Heinemann, and W. Hoffman. 1978. Community structure, distribution, and interrelationships of marine birds in the Gulf of Alaska. OCSEAP Final Rept. RU 108, Phase I.

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APPENDIX I

AVAILABILITY AND ACCESSIBILITY OF DATA SETS

1. Data Formats

As new biological data are generated, they are reported in tabular form in reports and simultaneously entered onto computer tapes. Both the MESA and WDOE data listed in Table I-B are, or will soon be, available in report form. The reports contain narrative descriptive information about the data, tabularized raw data, plots, and histograms. In addition, most of these data are also available on magnetic tape, where they were archived on standardized formats (refer to the next section on data acquisition).

2. Data Acquisition and What to Expect

a. Reports

MESA and OMPA Technical Reports and DOC/EPA Interagency reports found in Table I-A may be obtained from the Office of Marine Pollution Assessment, Pacific Office, RD/MPF25, 7600 Sand Point Way N.E., Bin C15700, Seattle, WA 98115 (206-527-6341; FTS 8-446-6341). Washington Department of Ecology (WDOE) reports are available from Mr. Fred Gardner, State of Washington, Department of Ecology, Olympia, WA 98504 (206-753-0577).

b. Magnetic Tapes

Most of the data identified in Table I-B are available on magnetic tape or diskette in one of two forms: (1) data received at the data centers that have undergone only preliminary editing and (2) data that have been subjected to some degree of editing and quality control and are considered final-processed. Most of the data sets can be retrieved as a specific file type, which is defined as a format for coding, processing, and exchanging a specific category of ecological and environmental data. Please refer to Table I-C for specific file type categories.

c. Tape Contents

Magnetic tape outputs can be obtained in one of two forms. The first (that most all file types may be obtained in) is the raw data retrieval, which consists of a format of coded information. The coded records contain file and station header information that indicate the unique file type, file identifier, cruise or field period dates, geographic location, etc. The physical or biological records contain the coded sampling methods, taxonomy, weights, counts, station physical parameters (water temp, sea state, tide information), or other information pertinent to a biological specimen's condition (external or internal). Further information on specific file types, copies of formats for specific files, programs for checking routines, and documentation may be obtained by contacting the Environmental Data and Information Service, or locally, the EDIS Pacific Northwest Liaison Office, Seattle, WA 98115 (206-527-6263; FTS 8-446-6263).

In addition, special products such as nonformatted listings or simple formatted tables have been developed for retrieval of Marine Birds (FT041), Marine Mammals (FT027), and the Intertidal/Shallow Subtidal Benthos (FT100) data sets. In these outputs data listings are arranged hierarchically and typically show the file type, investigator (FT100), tape track, site, location, dates sampled, sample elevation, gear type, biological name (taxonomy), counts, weights, and possibly some simple calculations such as biomass or abundance, or behavior as in the Marine Mammals (FT027).

Further inquiries as to data availability and how to order tapes or listings should be made by contacting:

U.S. Dept. of Commerce/NOAA
Environmental Data and Information Service
National Oceanographic Data Center
2001 Wisconsin Ave., N.W.
Washington, D. C. 20235
(202-634-7441; FTS 8-634-7441)

or locally the EDIS Pacific Northwest Liaison Office.

Additional information regarding MESA data sets, special products, costs for products, and file type summaries is found in the Data Catalog for the Marine Ecosystems Analysis Puget Sound Project, Distribution and Summarization of Digital Data (May 1980 ed.). Copies of this document are available from the OMPA Pacific Office or the EDIS Pacific Northwest Liaison Office.

Benthos, fish, plankton, bird, and mammal data were collected at the locations shown in Figures I-A through I-D and Table I-C.

3. Data Set Error Identification and Correction

Data sets received by the MESA Project from contractors are entered on cards or tape in the formats described above. They are initially checked for gross errors such as missing items, parity errors, and agreement with survey dates and locations. Some research groups performed their own data checks (see Mercer et al., 1978 for marine mammal data checking program).

Subsequent checking is performed with a series of programs implemented by machine. These checks are performed to ensure that the taxonomic codes are reasonable; that blank spaces are correct and do not represent omissions; that counts and weights are reasonable and within a preestablished valid range; that the biological measurements data match the field collection conditions data and vice versa; and that the codes used for sampling stations, gear types, sampling conditions, etc., are reasonable. Any questionable data sets or errors are resolved with the principal investigator and corrections are made to the data tapes by appropriate editing.

4. Data Management Recommendations

A number of things have been learned through trial and error regarding data management that may be of interest to managers of subsequent projects similar to this one. This assumes, though, that management elects to archive the data collected. Given the amount of time and difficulty experienced in this project in managing and archiving data, it may not be cost effective or worthwhile. If the data are to be manipulated sometime in the future or as a part of the reporting requirement; if the project is large and multidisciplinary; if computer facilities are readily available; and if the data are collected with standardized quantitative methods, then a data management/archival program is recommended.

a. Formats

Establish the framework for each data format very early in the project, based on the known kinds of data which will be collected. Finalize the details of the format(s) with the concurrence of the investigator(s). Keep the formats simple, as cluttered, detailed formats are difficult to use.

b. Investigators

Select the investigators, in part, on their ability to professionally meet data management requirements. Those with minimal previous experience, limited access to computer facilities, minimal interest in data archival, and little understanding of the resources required to properly manage data should be avoided.

c. Proposed plan

Review the investigator's data management plan to ensure that it meets the project requirements. Insist that the data management activities be an integral part of the overall investigator's management plan. Insist that data products (e.g, tapes) be provided on a regularly scheduled basis along with reports, meetings, etc. If necessary, provide in the contractual agreements that invoice payments will be predicated upon receipt of deliverables, including data products.

d. Quality control

Require early delivery of quality controlled digital data sets, ensuring that the investigator has checked his own data for accuracy and completeness.

e. Data checking

Either establish a data checking program or acquire an existing one for checking delivered data sets. Also devise a plan for getting corrections, if needed, from the investigators. It is critical to have sufficient time allowed in the contract(s) to review and check data sets, request corrections, receive and edit in corrections. Establish rigorous standards for required fields, codes, content, range checks, etc.

f. Availability

Provide equipment or facilities for manipulation of data sets, following their final editing. Further problems with data sets often become apparent when the data are actually used to solve a problem. For example, development of formatted tabular listing programs may turn up a problem with data completeness that escaped previous checks.

Table I-A. Publications resulting from NOAA/MESA and WDOE biological studies

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MESA

Chester, A. J., 1978. Microzooplankton in the surface waters of the Strait of Juan de Fuca. NOAA Technical Report ERL 403-PMEL 30, Pacific Marine Environmental Laboratory, Seattle, Washington, 26 pp. (NTIS PB-297233)

Chester, A. J., D. M. Damkaer, D. B. Dey, G. A. Heron, J. D. Larrance, 1980. Plankton of the Strait of Juan de Fuca, 1976-1977. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-80-032, U.S. Environmental Protection Agency, Washington, D. C., 64 pp. (NTIS PB80-190036)

Chester. A. J., D. M. Damkaer, D. B. Dey, and J. D. Larrance, 1977. Seasonal distributions of plankton in the Strait of Juan de Fuca. NOAA Technical Memorandum ERL MESA-24, Marine Ecosystems Analysis Program, Enviromental Research Laboratories, Boulder, Colorado, 71 pp. (NTIS PB-281833)

Cross, J. N., K. L. Fresh, B. S. Miller, C. A. Simenstad, S. N. Steinfort, and J. C. Fegley, 1978. Nearshore fish and macroinvertebrate assemblages along the STrait of Juan de Fuca including food habits of the common nearshore fish. NOAA Technical Memorandum ERL MESA-32, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 188 pp. (NTIS PB-292261)

Everitt, R. D., C. H. Fiscus, and R. L. DeLong, 1979. Marine mammals of northern Puget Sound and the Strait of Juan de Fuca - a report on investigations November 1, 1977-October 31, 1978. NOAA Technical Memorandum ERL MESA-41, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 191 pp. (NTIS PB-299287)

Everitt, R. D., C. H. Fiscus, and R. L. DeLong, 1980. Northern Puget Sound marine mammals. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-80-139, U.S. Environmental Protection Agency, Washington, D. C., 134 pp. (NTIS PB81-127516)

Gundlach, E. R., C. D. Getter, M. O. Hayes, 1980. Sensitivity of coastal environments to spilled oil, Strait of Juan de Fuca and northern Puget Sound. Informal Report. MESA Puget Sound Project, NOAA, Seattle, Washington, 76 pp.

Long, E. R., 1980. Physical processes and critical biological areas in the vicinity of a proposed petroleum transfer facility. Conference Record Oceans '80: Ocean Engineering in the '80s. Seattle, Washington, Sept. 9-10, 1980. IEEE Pub. No. 80CH1572-7, pp. 489-497, Institute of Electrical and Electronic Engineers, New York.

Table I-A (Contd.)

Manuwal, D. A., T. R. Wahl, and S. M. Speich, 1979. The seasonal distribution and abundance of marine bird populations in the Strait of Juan de Fuca and northern Puget Sound in 1978. NOAA Technical Memorandum ERL MESA-44, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 391 pp. (NTIS PB80-130859)

Miller, B. S., C. A. Simenstad, J. N. Cross, K. L. Fresh, and S. N. Steinfort, 1980. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of the common nearshore fish. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-80-027, U.S. Environmental Protection Agency, Washington, D. C., 211 pp. (NTIS PB81-155435, A11)

Nyblade, C. F., 1978. The intertidal and shallow subtidal benthos of the Strait of Juan de Fuca, spring 1976-winter 1977. NOAA Technical Memorandum ERL MESA-26, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 156 pp. (NTIS PB-285703)

Nyblade, C. F., 1979. The Strait of Juan de Fuca intertidal and subtidal benthos, second annual report, spring 1977-winter 1978. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-79-213, U.S. Environmental Protection Agency, Washington, D. C., 129 pp. (NTIS PB80-142136)

Schoener, A. and F. B. DeWalle, 1982. Effects of petroleum on selected uniform substrates: a feasibility study. NOAA Technical Memorandum OMPA-18, Office of Marine Pollution Assessment, Boulder, Colorado, 44 pp. (NTIS PB82-232927)

Simenstad, C. A., W. J. Kinney, B. S. Miller, 1980. Epibenthic zooplankton assemblages at selected sites along the Strait of Juan de Fuca. NOAA Technical Memorandum ERL MESA-46, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 73 pp. (NTIS PB80-209596)

Simenstad, C. A., B. S. Miller, J. N. Cross, K. L. Fresh, S. N. Steinfort, and J. C. Fegley, 1977. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of nearshore fish. NOAA Technical Memorandum ERL MESA-20, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 144 pp. (NTIS PB-297406)

Simenstad, C. A., B. S. Miller, C. F. Nyblade, K. Thornburgh, and L. J. Bledsoe, 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-79-259, U.S. Environmental Protection Agency, Washington, D. C., 335 pp. (NTIS PB80-169592)

Table I-A (Contd.)

Vanderhorst, J. R., J. W. Blaylock, P. Wilkinson, 1979. Research to investigate effects from Prudhoe Bay crude oil on intertidal infauna of the Strait of Juan de Fuca, first annual report. NOAA Technical Memorandum ERL MESA-45, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 38 pp. (NTIS PB80-160955)

Vanderhorst, J. R., J. W. Blaylock, P. Wilkinson, M. Wilkinson, and G. Fellingham, 1980. Recovery of Strait of Juan de Fuca intertidal habitat following experimental contamination with oil (second annual report fall 1979-winter 1980). DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-80-140, U.S. Environmental Protection Agency, Washington, D. C., 73 pp. (NTIS PB81-112518)

Vanderhorst, J. R., J. W. Blaylock, P. Wilkinson, M. Wilkinson, and G. Fellingham, 1981. Effects of experimental oiling on recovery of Strait of Juan de Fuca intertidal habitats. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-81-088, U.S. Environmental Protection Agency, Washington, D. C., 129 pp. (NTIS PB81-247165, A07)

Wahl, T. R., S. M. Speich, D. A. Manuwal, K. V. Hirsch, and C. Miller, 1981. Marine bird populations in the Strait of Juan de Fuca, Strait of Georgia and adjacent waters in 1978 and 1979. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-81-156, U.S. Environmental Protection Agency, Washington, D. C., 789 pp. (including 514 pp. microfiche Appendices).

Webber, H. H., 1979. The intertidal and shallow subtidal benthos of the west coast of Whidbey Island, spring 1977 to winter 1978, first year report. NOAA Technical Memorandum ERL MESA-37, Marine Ecosystems Analysis Program, Environmental Research Laboratories, Boulder, Colorado, 108 pp. (NTIS PB-295815)

Webber, H. H., 1980. Whidbey Island intertidal and shallow subtidal benthos. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-80-167, U.S. Environmental Protection Agency, Washington, D. C., (91 pp. + microfiche Appendix. (NTIS PB81-151441)

Webber, H. H., 1981. Growth rates of benthic algae and invertebrates in Puget Sound: I. Literature review, and II. Field studies on *Laminaria* and *Nereocystis*. NOAA Technical Memorandum OMPA-4, Office of Marine Pollution Assessment, Boulder, Colorado, 45 pp. (NTIS PB81-223760)

Zeh, J. E., J. P. Houghton, and D. C. Lees, 1981. Evaluation of existing marine intertidal and shallow subtidal biologic data. DOC/EPA Interagency Energy/Environment R&D Program Report EPA-600/7-81-036, U.S. Environmental Protection Agency, Washington, D. C., 262 pp. + microfiche Appendices. (NTIS PB82-134065)

Table I-A (Contd.)

WDOE

If NTIS number is not given, publication is available through DOE, State Library.

Beak Consultants, 1975. Biological oil impact literature review: Oil pollution and the significant biological resources of Puget Sound, Vol. I, Final Report, October 1975.

Beak Consultants, 1975. Biological oil impact literature review: Oil pollution and the significant biological resources of Puget Sound, Vol. II Bibliography, Final Report, October 1975.

Brittell, J. D., J. M. Brown, and R. L. Eaton (Eds.), 1976. Marine shoreline fauna of Washington, Vol. II. Washington State Department of Game, December 1976. (NTIS PB-265-978)

Eaton, R. L., 1975. Marine shoreline fauna of Washington, Vol. I. Washington State Department of Game, December 1975. (NTIS PB-254-294)

English, T. S., 1976. Oil pollution and the significant biological resources of Puget Sound, Open water study. University of Washington, Department of Oceanography, March 1976.

Gardner, F. (Ed.), 1977. North Puget Sound Baseline Study Main Report. 1974-1977 Washington State Department of Ecology.

Isakson, J. S. (Ed.), 1977. Washington coastal areas of major biological significance. Mathematical Sciences Northwest, Inc., November 1977.

Miller, B. S., 1978. Nearshore fishes, Puget Sound Baseline Program: Nearshore fish survey, University of Washington, College of Fisheries, January 1978.

Nyblade, C., 1977. Oil pollution and the significant biological resources of Puget Sound, North Puget Sound Intertidal Study, April 1977. University of Washington, Department of Zoology.

Salo, L. J., 1975. A baseline survey of significant marine birds in Washington State. Washington State Department of Game, September 1975. (NTIS PB-254-293)

WDOE, 1978. Five year intertidal community change San Juan Islands 1974-78 and the intertidal benthos of north Puget Sound, summer 1978.

Webber, B., 1978. W.W.U. Intertidal Report, September 1978. Huxley College, Western Washington University.

Table I-B. Biological synthesis report: Data sets

Type of Data	Years of Study	Completion Date	Investigator(s)	Form of Data	Data File Type
MESA					
Strait intertidal	2	Nov. 79	Nyblade	Tape; MESA Report-26; EPA Report 7-79-213	100
Whidbey intertidal	2	May 80	Webber	Tape; MESA Report-37; EPA Report 7-80-167	100
Strait fish	3	May 80	Miller/Simenstad	Tapes; MESA Report-20; MESA Report-32; EPA Report 7-80-027; Cross thesis	100
Whidbey fish	1	Dec. 78	Miller/Simenstad	Tape; MESA Report-32;	-
Marine birds	2	July 80	Manuwal/Wahl/Speich	Tapes; MESA Report-44; EPA Report 7-81-156	041
Marine mammals	2	May 80	Everitt/Fiscus/DeLong	Tapes; MESA Report-41; EPA Report 7-80-139	027
Strait plankton	2	Mar. 80	Chester	Tapes; MESA Report-24; EPA Report 7-80-032	024, 028, 029
Food webs	1	Sep. 79	Simenstad/Miller	EPA Report 7-79-259	
Oil effects, recovery	2	Sep. 80	Vanderhorst	MESA Report-45; EPA Reports 7-80-140 & 81-088	-
Epibenthic plankton	1	Apr. 80	Simenstad	MESA Report-46	-

Continued

Table I-B. (Contd.)

Type of Data	Years of Study	Completion Date	Investigator(s)	Form of Data	Data File Type
WDOE					
NPS plankton, larvae	1	Mar. 76	English	WDOE report	-
San Juan Island intertidal	7	June 81	Nyblade	WDOE reports: Oct. 75, Apr. 77 (tape), Aug. 79, Feb. 81, June 81	100
NPS intertidal	2	Sep. 78	Webber	WDOE report: App. K, Sep. 78; tape	100
NPS subtidal	2	Mar. 79	Smith	WDOE report: App. L, Mar. 79; tape	100
NPS fish	2	Jan. 78	Miller/Simenstad	WDOE reports: Feb. 76, Jan. 79; tape	
Fish data analyses	2	Jan. 79	Miller/students	Moulton thesis; Wingert thesis	
NPS baseline study	3	June 78	Gardner	WDOE report: June 78	
NPS fish		Jan. 79	Miller/Simenstad	WDOE final report #78070 FRI-UW 7901	
CPS fish		Feb. 79	Wingert/Terry/ Miller	WDOE final report #78062 FRI-UW 7903	

Table I-C. NODC file type formats for biological data collected in MESA studies.

File Type 024	Zooplankton
File Type 027	Marine Mammal Sighting 1
File Type 028	Phytoplankton Species
File Type 029	Primary Productivity
File Type 041	Marine Bird Survey
File Type 100	Intertidal/Subtidal

Table I-D. Sampling site names for Appendix Figure I-A.

INTERTIDAL/SUBTIDAL

Mixed Coarse

1. Legoe Bay
2. Guemes Island S.
3. Ebey's Landing
4. Twin Rivers
5. Dungeness Spit
6. South Beach
7. Deadman Bay

Sand

8. Eagle Cove
9. West Beach
10. North Beach
11. Kydaka Beach
12. Alexander's Beach

Mud-Gravel

13. Webb Camp
14. Beckett Point

Mud-Sand

15. Birch Bay
16. Jamestown/
Port Williams

Mud

17. Westcott Bay
18. Drayton Harbor
19. Padilla Bay
20. Fidalgo Bay

Exposed Rock

21. Pillar Point
22. Tongue Point

Protected Rock

23. Point Migley
24. Fidalgo Head
25. Cantilever Pier
26. Barnes Island
27. Point George
28. Allan Island

Cobble

29. Cherry Point
30. Shannon Point
31. Point Partridge
32. North Beach
33. Morse Creek

A. Neah Bay
B. Slip Point
C. Observatory Point

NEARSHORE

Exposed

34. Kydaka Beach
35. Twin Rivers
36. Morse Creek
37. Dungeness Spit
38. Jamestown/
Port Williams
39. Beckett Point
40. West Beach
41. Alexander's Beach
42. South Beach
43. Deadman Bay
44. Eagle Cove
45. Burrows Island

Protected

46. Birch Bay
47. Cherry Point
48. Lummi Bay
49. Point Migley
50. Legoe Bay
51. Guemes Island E.
52. Padilla Bay
53. Guemes Island S.
54. Shannon Point
55. Point George
56. Westcott Bay

OFFSHORE PLANKTON

Stations 1-9

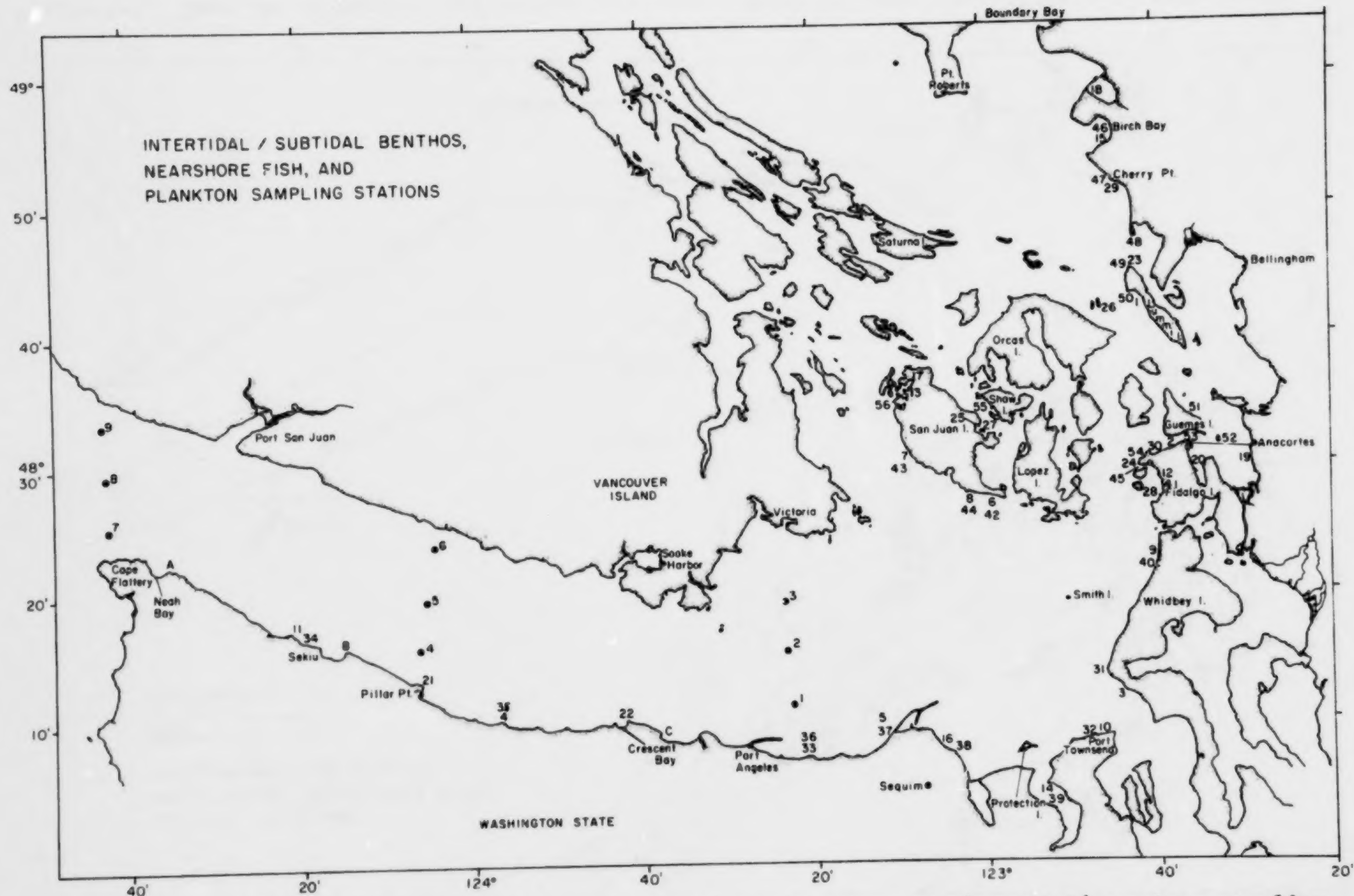
INTERTIDAL / SUBTIDAL BENTHOS, NEARSHORE FISH, AND PLANKTON SAMPLING STATIONS
Boundary Bay
Pt. Roberts
Birch Bay
Cherry Pt.
Bellingham
Saturna
Orcas I.
Shaw I.
San Juan I.
Lopez I.
Guemes I.
Anacortes
Fidalgo I.
Smith I.
Whidbey I.
Port Townsend
Protection I.
Sequim
Port Angeles
Crescent Bay
Victoria
Sooke Harbor
VANCOUVER ISLAND
Port San Juan
Cape Flattery
Neah Bay
Sekiu
Pillar Pt.
WASHINGTON STATE
49°
50'
40'
48° 30'
20'
10'
40'
20'
124°
40'
20'
123°
40'
20'

Figure I-A. Locations of plankton-collection sites(1-9) and intertidal/subtidal/nearshore sampling sites for benthos and fish(1-56).

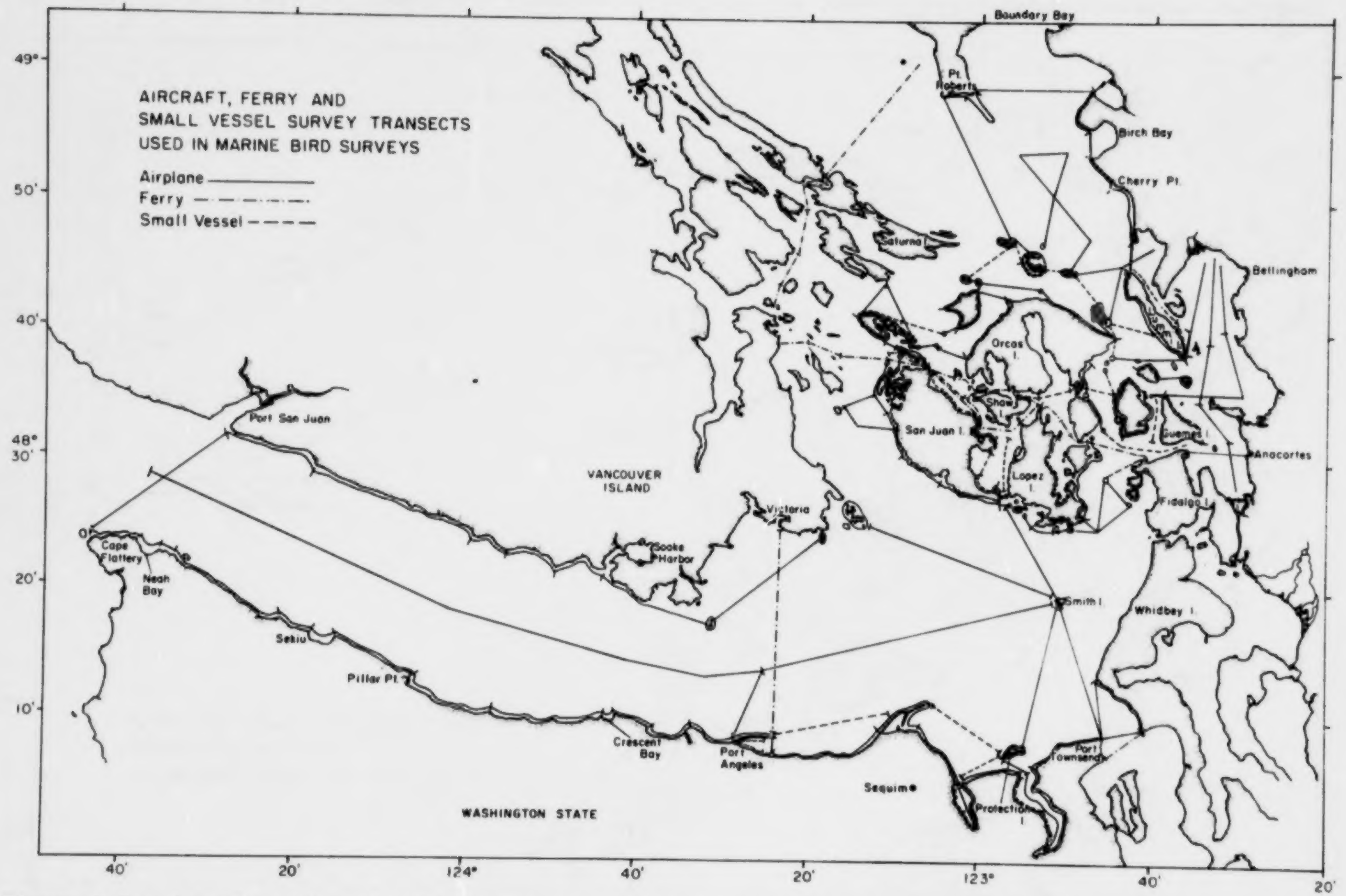
AIRCRAFT, FERRY AND
SMALL VESSEL SURVEY TRANSECTS
USED IN MARINE BIRD SURVEYS
Airplane
Ferry
Small Vessel
Boundary Bay
Pt. Roberts
Birch Bay
Cherry Pt.
Bellingham
Saturna I.
Orcas I.
Shaw I.
San Juan I.
Lopez I.
Guemes I.
Anacortes
Fidalgo I.
Smith I.
Whidbey I.
Port Townsend
Protection I.
Sequim
Port Angeles
Crescent Bay
Pillar Pt.
Sekiu
Neah Bay
Cape Flattery
Port San Juan
VANCOUVER ISLAND
Sooke Harbor
Victoria
WASHINGTON STATE
49°
50'
40'
48° 30'
20'
10'
40'
20'
124°
40'
20'
123°
40'
20'

Figure I-B. Location of marine bird survey transects. Note: in some areas where duplicate census methods were used, only one is shown for clarity.

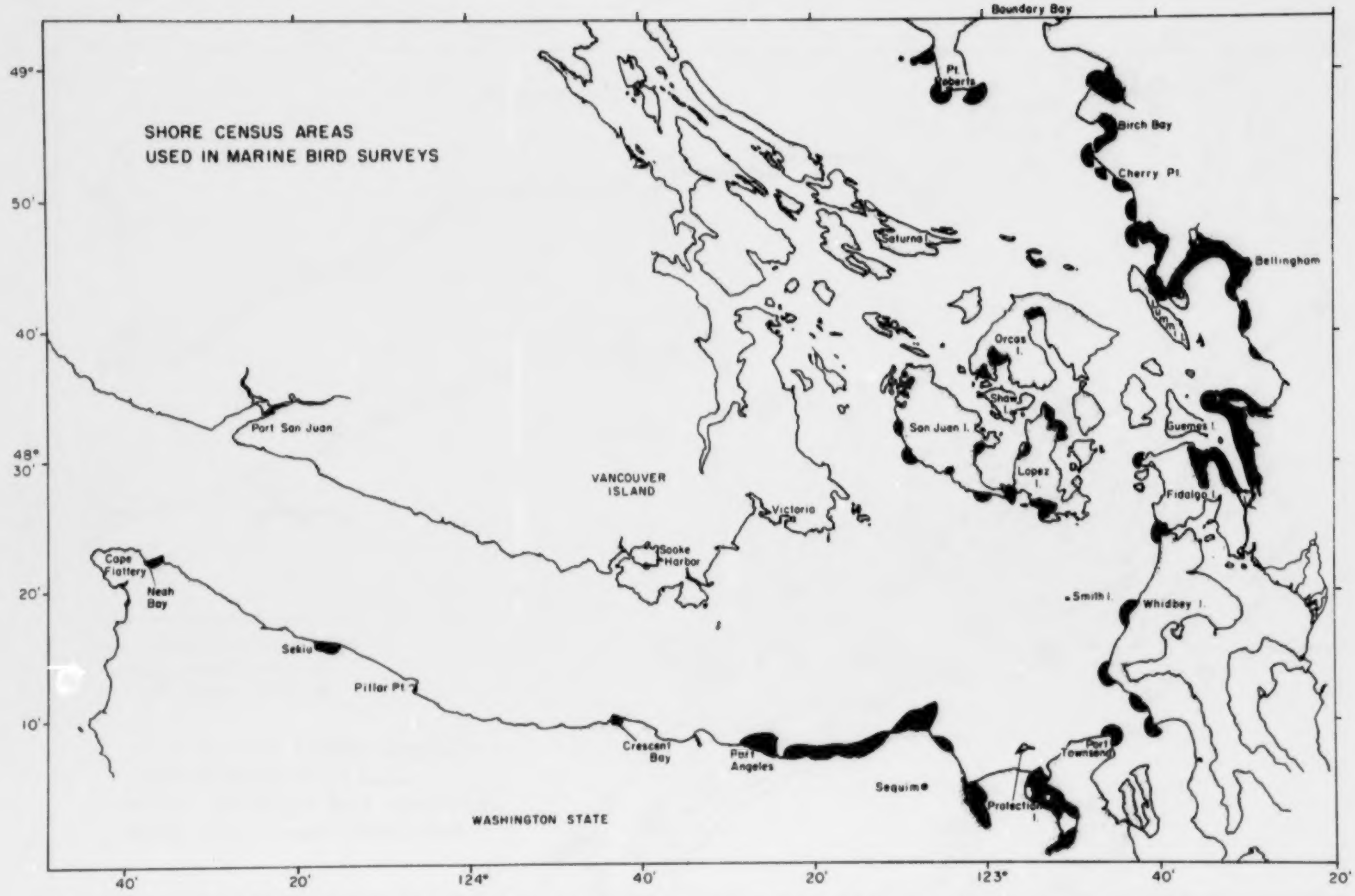
SHORE CENSUS AREAS
USED IN MARINE BIRD SURVEYS
Boundary Bay
Pt. Roberts
Birch Bay
Cherry Pt.
Saturna
Bellingham
Orcas I.
Shaw I.
San Juan I.
Lopez I.
Guemes I.
Fidalgo I.
Smith I.
Whidbey I.
Port San Juan
VANCOUVER ISLAND
Victoria
Sooke Harbor
Cape Flattery
Neah Bay
Sekiu
Pillar Pt.
Crescent Bay
Port Angeles
Sequim
Protection I.
Port Townsend
WASHINGTON STATE
49°
50'
40'
48° 30'
20'
10'
40'
20'
124°
40'
20'
123°
40'
20'

Figure I-C. Locations of marine bird shore census sites(darkened areas).

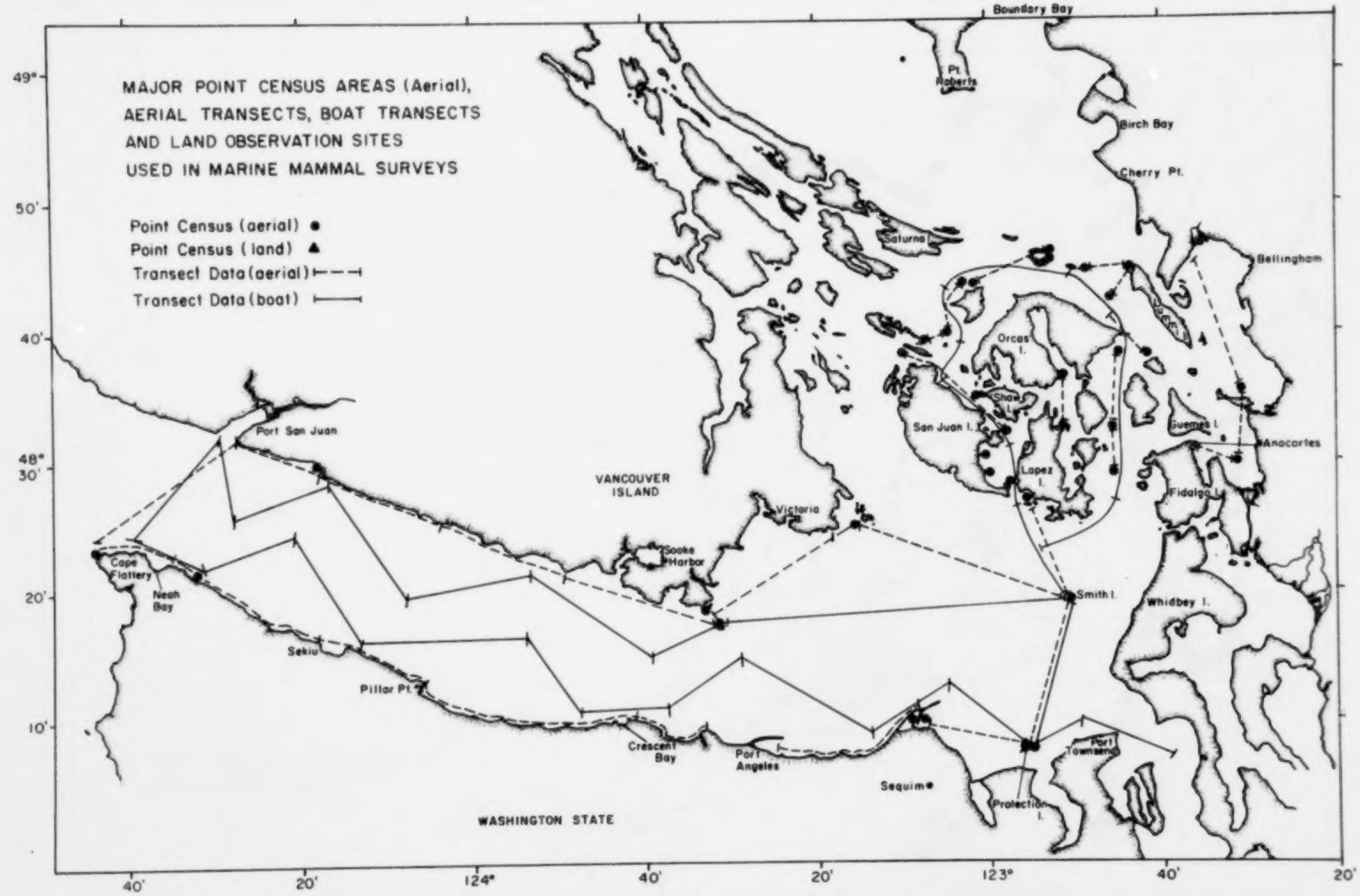
MAJOR POINT CENSUS AREAS (Aerial),
AERIAL TRANSECTS, BOAT TRANSECTS
AND LAND OBSERVATION SITES
USED IN MARINE MAMMAL SURVEYS
Point Census (aerial) ●
Point Census (land) ▲
Transect Data (aerial) ⊢ – – ⊣
Transect Data (boat) ⊢——⊣
Boundary Bay
Pt. Roberts
Birch Bay
Cherry Pt.
Bellingham
Saturna
Orcas I.
Shaw I.
San Juan I.
Lopez I.
Guemes I.
Anacortes
Fidalgo I.
Whidbey I.
Smith I.
Victoria
Sooke Harbor
VANCOUVER ISLAND
Port San Juan
Cape Flattery
Neah Bay
Sekiu
Pillar Pt.
Crescent Bay
Port Angeles
Sequim
Port Townsend
Protection I.
WASHINGTON STATE
49°
50'
40'
48° 30'
20'
10'
40'
20'
124°
40'
20'
123°
40'
20'

Figure I-D. Locations of marine mammal survey sites and transects.

APPENDIX II

DOMINANT SPECIES PER INTERTIDAL/SUBTIDAL HABITAT TYPE AND REPRESENTATIVE DATA FROM SPECIFIC SAMPLING SITES

Mammals data are shown as highest single counts made during a two-year study period at selected sites.

Birds data are shown as mean numbers and biomass per square kilometer calculated seasonally over a two-year study period for selected survey areas for the 10 most common (by percent occurrence) species. If fewer than 10 species were observed, density and biomass are shown for the number of species observed.

Fish data are shown as present (X) or absent for most common species at selected sites.

Benthos data are shown as mean wet weight (in grams/m^2) for plants; and mean counts/m^2 (above) and mean wet weight (grams/m^2) (below) for invertebrates. Dominants were subjectively selected from lists of species that comprised at least 10% of the total weight or counts at each site. Abbreviations of pre (predator), sus (suspension feeder), her (herbivore), sca (scavenger), dep (deposit feeder) are included for those taxa whose feeding habits are known.

Table II-A. Dominant species of marine mammals

Rock/cobble

	Sucia Island	Race Rocks	Patos Island	Tatoosh Island
Harbor seal (*Phoca vitulina*)	124	135	X*	3
Northern sea lion (*Eumetopias jubatus*)	32	212	10	20
California sea lion (*Zalophus californianus*)	0	296	0	0

*present, but unquantified.

Exposed unconsolidated

	Dungeness Spit	Smith-Minor Islands	Protection Island
Harbor seal	87	257	223
Northern sea lion	0	0	0
California sea lion	0	0	0

Protected unconsolidated

	Padilla Bay	Samish Bay	Dungeness Bay
Harbor seal	93	71	107
Northern sea lion	0	0	0
California sea lion	0	0	0

NOTE: Numbers observed - highest single count.

Table II-B. Dominant species of marine birds

Rock/cobble

	Spring (n = 49)			Summer (n = 16)	
	No./km^2	g/km^2		No./km^2	g/km^2
Greater Scaup	12	11	Great Blue Heron	< 1	< 1
Common Goldeneye	<1	<1	Mallard	< 1	< 1
Bufflehead	2	<1	Harlequin Duck	3	2
Oldsquaw	6	5	White-winged Scoter	1	1
Harlequin Duck	3	2	Surf Scoter	9	9
White-winged Scoter	27	38	Killdeer	< 1	0
Surf Scoter	1,090	1,036	Glaucous-winged Gull	13	17
Glaucous-winged Gull	30	40	California Gull	< 1	< 1
Mew Gull	19	8	Mew Gull	< 1	< 1
Bonaparte's Gull	89	16	Bonaparte's Gull	< 1	< 1

	Fall (n = 65)			Winter (n = 54)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	< 1	< 1	Greater Scaup	10	9
Harlequin Duck	2	< 1	Common Goldeneye	3	2
White-winged Scoter	< 1	1	Bufflehead	8	3
Surf Scoter	8	8	Oldsquaw	2	2
Sanderling	< 1	< 1	Harlequin Duck	1	< 1
Glaucous-winged Gull	9	12	White-winged Scoter	1	1
California Gull	1	< 1	Surf Scoter	25	24
Mew Gull	1	< 1	Glaucous-winged Gull	9	11
Bonaparte's Gull	7	1	Mew Gull	2	1
Heermann's Gull	6	2	Bonaparte's Gull	< 1	< 1

NOTE: Mean No./km^2 and mean g/km^2 for 10 most-frequently occurring species.

Continued

Table II-B. (Contd.)

Exposed unconsolidated

	Spring (n = 4)			Summer (n = 3)	
	No./km^2	g/km^2		No./km^2	g/km^2
Common Goldeneye	3	3	Bald Eagle	< 1	4
Bufflehead	5	2	Killdeer	< 1	< 1
White-winged Scoter	2	3	Glaucous-winged Gull	44	58
Surf Scoter	6	6	California Gull	< 1	< 1
Bald Eagle	< 1	4			
Glaucous-winged Gull	15	19			
Mew Gull	< 1	< 1			
Bonaparte's Gull	20	4			

	Fall (n = 10)			Winter (n = 7)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	< 1	< 1	Great Blue Heron	1	3
White-winged Scoter	1	2	Common Goldeneye	< 1	< 1
Surf Scoter	17	16	Bufflehead	16	6
Bald Eagle	< 1	1	Oldsquaw	2	2
Glaucous-winged Gull	103	134	Harlequin Duck	8	5
California Gull	10	8	White-winged Scoter	< 1	< 1
Mew Gull	68	29	Surf Scoter	8	8
Bonaparte's Gull	44	8	Glaucous-winged Gull	26	34
Heermann's Gull	27	12	Mew Gull	7	3
Common Tern	50	5	Bonaparte's Gull	3	< 1

NOTE: Mean No./km^2 and mean g/km^2 for 10 most-frequently occurring species.

Continued

Table II-B. (Contd.)

Mixed coarse

	Spring (n = 49)			Summer (n = 15)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Scaup	2	2	Great Blue Heron	1	3
Common Goldeneye	2	2	Greater Scaup	< 1	< 1
Bufflehead	15	6	Harlequin Duck	2	1
Oldsquaw	< 1	< 1	White-winged Scoter	< 1	1
Harlequin Duck	< 1	< 1	Surf Scoter	7	6
White-winged Scoter	2	3	Bald Eagle	< 1	< 1
Surf Scoter	13	13	Killdeer	< 1	0
Black Scoter	2	2	Glaucous-winged Gull	33	43
Glaucous-winged Gull	58	75	California Gull	< 1	< 1
Mew Gull	5	2	Bonaparte's Gull	2	< 1

	Fall (n = 81)			Winter (n = 87)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	< 1	2	Greater Scaup	7	6
Harlequin Duck	< 1	< 1	Common Goldeneye	12	10
White-winged Scoter	8	11	Bufflehead	37	15
Surf Scoter	10	10	Oldsquaw	17	13
Glaucous-winged Gull	56	72	Harlequin Duck	3	2
Western Gull	< 1	< 1	White-winged Scoter	3	5
California Gull	48	37	Surf Scoter	17	16
Mew Gull	14	6	Black Scoter	3	3
Bonaparte's Gull	21	4	Glaucous-winged Gull	112	146
Heermann's Gull	13	6	Mew Gull	47	20

NOTE: Mean No./km^2 and mean g/km^2 for 10 most-frequently occurring species.

Continued

Table II-B. (Contd.)

Protected unconsolidated (mud-sand)

	Spring (n = 14)			Summer (n = 2)	
	No./km^2	g/km^2		No./km^2	g/km^2
Black Brant	276	345	Great Blue Heron	4	13
American Wigeon	32	25	Killdeer	1	< 1
Greater Scaup	13	12	Black Turnstone	22	3
Common Goldeneye	11	9	Glaucous-winged Gull	354	461
Bufflehead	58	23			
White-winged Scoter	15	21			
Surf Scoter	22	21			
Black Bellied Plover	4	1			
Glaucous-winged Gull	142	184			
Mew Gull	26	11			

	Fall (n = 20)			Winter (n = 27)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	4	12	Black Brant	122	153
American Wigeon	752	602	American Wigeon	411	329
White-winged Scoter	11	15	Greater Scaup	43	38
Surf Scoter	29	27	Common Goldeneye	23	20
Killdeer	< 1	< 1	Bufflehead	244	98
Glaucous-winged Gull	109	141	Harlequin Duck	1	< 1
California Gull	84	65	White-winged Scoter	15	20
Mew Gull	7	3	Surf Scoter	76	73
Bonaparte's Gull	19	3	Glaucous-winged Gull	37	48
Heermann's Gull	2	1	Mew Gull	22	9

NOTE: Mean No./km^2 and mean g/km^2 for 10 most-frequently occurring species.

Continued

Table II-B. (Contd.)

Protected unconsolidated (mud)

	Spring (n = 43)			Summer (n = 17)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	2	5	Great Blue Heron	7	20
Black Brant	147	184	Mallard	< 1	< 1
Greater Scaup	65	59	Greater Scaup	3	3
Common Goldeneye	2	1	White-winged Scoter	1	2
Bufflehead	23	9	Surf Scoter	2	2
Oldsquaw	< 1	< 1	Bald Eagle	< 1	< 1
White-winged Scoter	6	9	Killdeer	< 1	< 1
Surf Scoter	74	70	Glaucous-winged Gull	42	54
Glaucous-winged Gull	22	29	Ring-billed Gull	< 1	< 1
Mew Gull	7	3	Bonaparte's Gull	9	2

	Fall (n = 72)			Winter (n = 82)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	5	15	Common Pintail	49	47
Greater Scaup	47	43	American Wigeon	65	52
White-winged Scoter	10	14	Greater Scaup	68	61
Surf Scoter	19	18	Common Goldeneye	8	7
Killdeer	< 1	< 1	Bufflehead	60	24
Glaucous-winged Gull	20	26	White-winged Scoter	10	14
California Gull	3	2	Surf Scoter	20	19
Ring-billed Gull	5	3	Dunlin	93	6
Mew Gull	7	3	Glaucous-winged Gull	15	19
Bonaparte's Gull	30	5	Mew Gull	8	3

NOTE: Mean No./km^2 and mean g/km^2 for 10 most-frequently occurring species.

Continued

Table II-B. (Contd.)

Protected unconsolidated (mud-gravel)

	Spring (n = 11)			Summer (n = 2)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	< 1	1	Great Blue Heron	2	4
Black Brant	12	15	Harlequin Duck	< 1	< 1
Greater Scaup	34	30	White-winged Scoter	< 1	< 1
Common Goldeneye	< 1	< 1	Surf Scoter	< 1	< 1
Bufflehead	21	9	Glaucous-winged Gull	14	19
White-winged Scoter	43	60	Bonaparte's Gull	< 1	< 1
Surf Scoter	122	116			
Black Brant	2	2			
Glaucous-winged Gull	37	48			
Mew Gull	1	< 1			

	Fall (n = 9)			Winter (n = 12)	
	No./km^2	g/km^2		No./km^2	g/km^2
Great Blue Heron	< 1	3	Common Pintail	1	2
American Wigeon	1	1	American Wigeon	12	10
White-winged Scoter	13	18	Greater Scaup	172	154
Surf Scoter	9	9	Common Goldeneye	58	50
Western Sandpiper	< 1	< 1	Bufflehead	101	40
Glaucous-winged Gull	29	33	Oldsquaw	63	49
California Gull	4	3	White-winged Scoter	53	73
Mew Gull	< 1	< 1	Surf Scoter	141	134
Bonaparte's Gull	8	1	Glaucous-winged Gull	32	42
Heermann's Gull	< 1	< 1	Mew Gull	14	6

NOTE: Mean No./km^2 and mean g/km^2 for 10 most-frequently occurring species.

Table II-C. Dominant species of fish

Exposed sand

	Eagle Cove	Alexander's Beach	West Beach	Kydaka Beach
Microgadus proximus (Pacific tomcod-juv.)	X	X	X	
Amphisticus rhodoterus (redtail surfperch)				X
Cymatogaster aggregata (shiner perch)	X	X	X	
Blepsias cirrhosus (silverspotted sculpin)		X		
Leptocottus armatus (Pacific staghorn sculpin)	X	X	X	X
Agonus acipenserinus (sturgeon poacher)		X	X	
Citharichthys stigmaeus (speckled sanddab)				X
Lepidopsetta bilineata (rock sole)			X	
Platichthys stellatus (starry flounder)	X	X	X	
Parophrys vetulus (English sole-juv.)	X	X	X	X
Psettichthys melanostictus (sand sole)	X	X		X

NOTE: Sites at which dominant species were present.

Continued

Table II-C. (Contd.)

Exposed mixed coarse

	Cherry Point	Legoe Bay	Guemes Island	Deadman Bay	South Beach	Dungeness Spit	Twin Rivers
Microgadus proximus (Pacific tomcod-juv.)		X	X		X	X	
Theragra chalcogramma (walleye pollock-juv.)			X		X		
Aulorhynchus flavidus (tubesnout)		X		X			
Syngnathus leptonhynehus (bay pipefish)		X		X			
Amphisticus rhodoterus (redtail surfperch)							X
Cymatogaster aggregata (shiner perch)	X		X	X	X	X	
Embiotoca lateralis (striped seaperch)			X				X
Rhacochilus vacca (pile perch)		X	X				
Apodichthys flavidus (penpoint gunnel)	X	X		X			X
Pholis laeta (crescent gunnel)		X	X	X			X
P. ornata (saddleback gunnel)		X					X
Hexagrammos stelleri (whitespotted greenling)	X	X	X	X			
Sebastes caurinus (copper rockfish-juv.)				X			
Artedius fenestralis (padded sculpin)	X	X	X	X	X		X
A. lateralis (smoothhead sculpin)				X			
Ascelichthys rhodorus (rosylip sculpin)					X		
Blepsias cirrhosus (silverspotted sculpin)	X	X		X			X
Clinocottus acuticeps (sharpnose sculpin)		X	X		X		
Enophrys bison (buffalo sculpin)	X	X	X	X	X		X
Leptocottus armatus (Pacific staghorn sculpin)	X	X	X	X	X	X	X

Continued

Table II-C. (Contd.)

Exposed mixed coarse

	Cherry Point	Legoe Bay	Guemes Island	Deadman Bay	South Beach	Dungeness Spit	Twin Rivers
Myoxocephalus polyacanthocephalus (great sculpin)	X	X	X	X	X		
Oligocottus maculosus (tidepool sculpin)	X	X		X	X		
Scorpaenichthys marmoratus (cabezon-juv.)	X	X	X				
Synchirus gilli (manacled sculpin)				X			
Eumicrotremis orbis (spiny lumpsucker)				X	X		
Liparis callyodon (spotted snailfish)	X			X			
L. florae (tidepool snailfish)			X				
L. rutteri (ringtail snailfish)				X	X		
Agonus acipenserinus (sturgeon poacher)		X	X		X		
Pallasina barbata (tubenose poacher)	X	X	X	X			X
Citharichthys sordidus (Pacific sanddab)	X						
Lepidopsetta bilineata (rock sole)		X			X		
Parophrys vetulus (English sole-juv.)			X	X	X	X	X
Platichthys stellatus (starry flounder)		X	X		X	X	X
Psettichthys melanostictus (sand sole)						X	X

NOTE: Sites at which dominant species were present.

Table II-C. (Contd.)

Exposed rock/cobble

	Neah Bay	Slip Point	Observatory Point	Morse Creek	Twin Rivers	North Beach
Anoplarchus purpurescens (high cockscomb)	X	X	X	X		
Clinoccottus embryum (calico sculpin)		X	X			
C. globiceps (mosshead sculpin)		X	X			
Oligocottus maculosus (tidepool sculpin)	X	X	X	X	X	X
Gobiesox maeandricus (northern clingfish)	X	X	X	X	X	X
Xiphister atropurpureus (black prickleback)		X				

NOTE: Sites at which dominant species were present.

Rocky kelp bed(subtidal)

	Barnes Island	Allan Island	Point George
Embiotoca lateralis (striped seaperch)	X		X
Sebastes caurinus (copper rockfish)	X	X	X
S. emphaeus (Puget Sound rockfish)			X
S. flavidus (yellowtail rockfish)		X	
S. maliger (quillback rockfish)	X		X
S. melanops (black rockfish)		X	X
Hexagrammos decagrammus (kelp greenling)	X	X	X
Ophiodon elongatus (lingcod)	X		X
Artedius harringtoni (scalyhead sculpin)		X	
Hemilepidotus hemilepidotus (red Irish lord)		X	
Jordania zonope (longfin sculpin)	X	X	X
Coryphopterus nicholsi (blackeye goby)	X	X	

NOTE: Sites at which dominant species were present.

Table II-C. (Contd.)

Protected unconslidated (mud/gravel)

	Birch Bay	Fidalgo Island	Westcott Bay	Beckett Point	Jamestown/Port Williams
Microgadus proximus (Pacific tomcod-juv.)	X			X	
Aulorhynchus flavidus (tube-snout)	X		X	X	
Syngnathus leptonhynehus (bay pipefish)	X	X	X		
Cymatogaster aggregata (shiner perch)	X	X	X	X	X
Embiotoca lateralis (striped seaperch)				X	
Rhacochilus vacca (pile perch)	X				
Apodichthys flavidus (penpoint gunnel)			X		
Lumpenus sagitta (snake prickleback)	X				
Pholis laeta (crescent gunnel)		X			
Pholis ornata (saddleback gunnel)	X	X	X		
Hexagrammos stelleri (whitespotted greenling)	X				
Artedius fenestralis (padded sculpin)		X	X	X	X
Blepsias cirrhosus (silverspotted sculpin)	X	X	X		X
Chitonotis pugetensis (roughback sculpin)				X	
Clinocottus acuticeps (sharpnose sculpin)	X	X	X		X
Enorphrys bison (buffalo sculpin)	X	X		X	
Leptocottus armatus (Pacific staghorn sculpin)	X	X	X	X	X
Myoxocephalus polyacanthocephalus (great sculpin)	X			X	
Oligocottus maculosus (tidepool sculpin)	X	X	X		X
Scorpaenichthys marmoratus (cabezon)	X		X		

Continued

Table II-C. (Contd.)

Protected unconslidated (mud/gravel)

	Birch Bay	Fidalgo Island	Westcott Bay	Beckett Point	Jamestown/Port Williams
Agonus acipenserinus (sturgeon poacher)	X		X		
Pallasina barbata (tubenose poacher)		X			X
Eumicrotremus orbis (spiny lumpsucker)			X		
Citharichthys sordidus (Pacific sanddab)	X				
Lepidopsetta bilineata (rock sole)	X				
Parophrys vetulus (English sole-juv.)	X	X	X	X	X
Platichthys stellatus (starry flounder)	X	X	X	X	X
Psettichthus melanostictus (sand sole)	X				

NOTE: Sites at which dominant species were present.

Table II-D. Dominant species of intertidal benthos - a. Intertidal rock

	Tongue Point	Pillar Point	Fidalgo Head	Cantilever Pier	Migley Point
Chlorophyta					
Enteromorpha spp.			31.9	8.7	19.9
Monostroma spp.			25.2	2.1	44.0
Ulva spp.			65.5	20.8	84.9
Phaeophyta					
Alaria spp.	1473.4	1574.8	54.4	1.0	0.2
Egregia menziesii		540.5			
Fucus distichus			845.0	383.7	1738.6
Hedophyllum sessile	67.3	477.3		0.1	
Rhodophyta					
Bossiella plumosa	145.8		0.9		2.2
Ceramium pacificum			5.2	0.4	
Corallina vancouveriensis	277.5	6.7	2.0		0.4
Endocladia muricata	17.5		9.4	3.7	3.9
Gigartina spp.	28.3	14.3	14.3	17.1	1051.4
Halosaccion glandiforme	114.3	3.3		4.6	
Iridaea spp.	70.4	261.3	15.7	3.3	30.8
Microcladia borealis			47.8	0.5	2015.1
Odonthalia flocossa	13.3	73.3	48.1		25.8
Polysiphonia spp.			19.2	1.0	158.0
Porphyra spp.	1.4		13.1	1.7	53.7
Angiosperm					
Phyllospadix scouleri	881.1	2039.8			
Coelenterata					
Anthopleura elegantissima	55.8				11.7
pre.	59.2				21.8

Continued

Table II-D. (Contd.) a. Intertidal rock

	Tongue Point	Pillar Point	Fidalgo Head	Cantilever Pier	Migley Point
Nemertea spp. pre.		50.0 3.3	0.7	0.1	49.0 3.2
Nematoda spp. dep.	1017.5 6.7	3060.0 6.7	0.2	5.9	
Oligochaeta dep.	1385.0 6.7	590.0 1.7	2.5	0.4	
Polychaeta					
Arenicolidae spp. dep.		683.3			
Cirratulidae					
Cirratulus sp. dep.	53.3 1.7		2.2		9.6 0.4
Lumbrineridae					
Lumbrineris spp. dep.		160.0			1.2 0.1
Nereidae					
Nereis spp. her.	168.3 6.7		6.4		7.1 0.2
Sabellidae spp. sus.	450.0 21.7	176.7 16.7		0.4	1.4 0.1
Serpulidae					
Spirorbis sp. sus.			2.0	0.5	52.7 0.1
Spionidae spp. dep.		310.5 16.7	0.6		6.3 0.2
Syllidae	1818.3 32.5	216.7 26.7	5.7	2.8	96.5 1.9
Terebellidae spp. dep.	443.3 5.0		17.0 0.3		4.2 0.3

Continued

Table II-D. (Contd.) a. Intertidal rock

	Tongue Point	Pillar Point	Fidalgo Head	Cantilever Pier	Migley Point
Mollusca - Amphineura					
Cyanoplax dentiens her.	24.2	0.5	22.7	1.9	12.0
	2.5	0.2	129.2		0.7
Katherina tunicata her.	4.4	6.3	10.0	2.1	
	23.4	98.3	94.7		
Mopalia spp. her.			0.8	0.4	0.7
			1.0		2.8
Tonicella lineata her.	6.7	8.3	0.7	1.1	0.2
	4.9	0.2	2.1		
Mollusca Gastropoda					
Collisella digitalis her.	100.8	40.0	20.7	51.1	90.4
	19.0	13.7	4.4		11.8
Collisella pelta her.	25.0		54.0	278.1	109.7
	19.3		10.2		5.3
Collisella strigitella her.	49.2		1.3	213.9	26.4
	4.1		0.2		0.5
Lacuna variegata her.	18.3	6.7	1132.3	81.2	84.2
	3.3	3.3	5.6		1.3
Littorina scutulata her.		70.0	79.0	829.3	1304.7
		0.2	8.7		43.0
Littorina sitkana her.	1159.2	363.3	46.0	178.0	135.0
	6.7	6.7	4.5		6.0
Notoacmea persona her.			24.7		108.3
			7.5		3.3
Notoacmea scutum her.	6.7		20.0	2.7	6.3
	1.2		11.5		0.7
Nucella spp. pre.	7.5	6.7	12.4	12.0	1.2
	3.8	6.7	7.3		0.2
Searlesia dira			17.1	4.8	0.2
			20.9		0.1

Continued

Table II-D. (Contd.) a. Intertidal rock

	Tongue Point	Pillar Point	Fidalgo Head	Cantilever Pier	Migley Point
Mollusca - Bivalvia					
Hiatella spp. sus.	11.7	13.3		0.2	
Musculus pygmaeus sus.	10225.8				
Mytilus edulis sus.				137.0	1911.8 157.5
Mytilus spp. sus.	80.8	40.8	46.7 0.9		
Crustacea - Tanaidacea					
Anatanais normani dep.	497.5 6.7	13.3 3.3	1.9		
Leptochelia dubia dep.		720.0 0.3			0.3
Pancolus californiensis dep.	669.2 6.7		1.5		
Crustacea Cirripedia					
Balanus cariosus sus.	48.3 66.9		1710.8 1357.2	230.2	56.0 73.3
Balanus crenatus/Balanus glandula sus.		590.0 23.3	176.2 17.4	505.0	4081.8 451.5
Balanus spp. sus.	2633.0 161.0	140.5 284.8	32.9 1.1	612.6	3603.1 154.8
Cthamalus dalli sus.	1180.0 24.8	2486.7 63.3	30.5 0.3	522.3	2041.9 63.0
Crustacea - Amphipods					
Caprellidea sp.		100.0 6.7			

Continued

Table II-D. (Contd.) a. Intertidal rock

	Tongue Point	Pillar Point	Fidalgo Head	Cantilever Pier	Migley Point
Crustacea - Amphipods (Contd.)					
Gammaridea spp. dep./her.	2760.0	226.7	837.2	246.4	350.6
	22.8	7.3	4.8		4.0
(*Ampithoe* sp.)					
(*Hyale* sp.)					
(*Parallorchestes ochotensis*)					
(*Pontogeneia* sp.)					
Crustacea - Isopoda					
Dynamenella sheareri sca.	991.7	183.3	166.4	62.6	52.7
	9.2	3.3	0.7		0.6
Exosphaeroma spp. sca.			73.3	1.6	117.6
			0.4		1.3
Gnorimosphaeroma oregonensis sca.			76.4	1.1	3.5
			1.0		0.1
Idotea spp. sca.	10.0	87.2	144.2	3.1	17.2
	1.5	7.3	5.7		1.7
Limnoria algarum her.	28.3		1.0		
	3.3				
Munna chromatocephala dep.		263.3			
		3.3			
Crustacea - Decapoda					
Cancer oregonensis pre.	3.3	0.8	1.1	0.4	
	8.3	0.5	0.4		
Pagurus spp. dep.	5.8		58.8	89.4	51.5
	1.0		4.4		2.3
Pugettia gracilis her.	140.0	3.3	81.1	2.4	4.7
	5.0	4.3	3.9		0.7

Continued

Table II-D. (Contd.) a. Intertidal rock

	Tongue Point	Pillar Point	Fidalgo Head	Cantilever Pier	Migley Point
Insecta					
Diptera larvae spp.	709.2	100.0	55.5	144.3	18.8
dep.	10.0	6.7	0.1		0.7
Echinodermata - Asteroidea					
Leptasterias hexactis pre.	10.0		5.4	3.1	15.0
	5.8		1.9		2.9
Echinodermata - Holothuroidea					
Cucumaria pseudocurata sus.	1503.3				
	42.5				

Continued

Table II-D. (Contd.) b. Intertidal cobble

	Morse Creek	North Beach	Partridge Point	Shannon Point	Cherry Point
Chlorophyta					
Enteromorpha spp.			7.9	157.2	280.3
Monostroma spp.			5.3	20.3	42.7
Spongomorpha spp.			4.6	9.4	17.9
Ulva spp.	15.7	30.0	19.4	173.6	472.6
Phaeophyta					
Alaria spp.	297.7	237.7	241.9		3.6
Fucus distichus	17.8			194.2	13.4
Hedophyllum sessile	6.4		11.3		
Nereocystis leutkeana		52.2			
Rhodophyta					
Gigartina papillata	50.0	15.0	39.9	305.4	123.7
Iridea spp.	537.8	136.5	78.1	45.8	1.3
Odonthalia floccosa			31.8	10.6	14.5
Polysiphonia spp.			1.7	97.7	2.9
Porphyra spp.			8.0	1.2	4.5
Pterosiphonia bipinnata		58.0		0.3	0.6
Rhodomela larix			50.9	444.5	20.4
Angiosperms					
Zostera marina			0.1	54.4	1.1
Coelenterata					
Anthopleura artemesia pre.				5.3 3.9	4.9 50.2
Anthopleura elegantissima pre.	21.7 1.9	2.8 1.0	43.4 34.0	13.0 10.3	
Platyhelminthes					
Turbellaria pre.	157.5 3.0		23.7		7.5 0.1

Continued

Table II-D. (Contd.) b. Intertidal cobble

	Morse Creek	North Beach	Partridge Point	Shannon Point	Cherry Point
Nemertea spp. pre.	218.8 5.6		129.7 1.3	29.5 1.2	80.1 1.2
Nematoda spp. dep.	126.7 4.0		485.1 0.3	8.2 0.1	31.5 0.1
Oligochaeta spp. dep.	6.3 0.7	180.7 4.7	1797.6 0.4	195.4 1.5	756.1 1.5
Polychaeta					
Arenicolidae spp. sus./dep.	71.6 1.8				0.1
Capitellidae					
Capitella capitata dep.	682.2 4.2		19.9 0.2	4.4	4.5
Mediomastus sp. dep.			7.6	7.4	36.4 0.1
Notomastus tenuis dep.			9.3 0.6	114.2 6.2	139.4 4.3
Dorvilleidae					
Protodorvillea gracilis pre.			739.0 0.2		0.2
Glyceridae					
Hemipodus borealis pre.		40.0 0.7		17.4 1.9	32.7 1.8
Goniadidae					
Glycinde picta pre.			0.3	22.6 0.7	29.2 0.3
Lumbrineridae					
Lumbrineris sp. dep.			57.0 8.9	32.1 3.2	9.0 1.4

Continued

Table II-D. (Contd.) b. Intertidal cobble

	Morse Creek	North Beach	Partridge Point	Shannon Point	Cherry Point
Polychaeta (Contd.)					
Nereidae					
Nereis sp. her.	143.8	45.3	26.3	26.7	36.1
	14.0	4.7	6.7	4.3	16.3
Platynereis bicanaliculata			117.7	1.9	3.4
her.			1.7	.1	.1
Onuphidae					
Onuphis spp. sca.		33.3	552.3	44.2	
		0.7	4.7	0.9	
Opheliidae					
Armandia brevis dep.	30.4		6.1	16.1	79.8
	1.6			0.3	1.0
Sabellidae spp. sus.	2145.3			3.2	0.8
	18.0			0.3	0.1
Spionidae					
Malacoceros sp. dep.	521.7	90.0	7.4	8.6	0.6
	2.3	3.3			
Polydora spp. dep.		25.3	1.4	6.5	20.2
		0.7		0.1	0.3
Syllidae pre.		42.0	412.9	22.6	10.6
		0.7	0.7	1.4	
Terebellidae spp. dep./sus.			107.4	17.5	0.6
			5.2	12.0	0.2
Thelepus crispus dep.			300.8	67.9	
			85.0	70.3	
Mollusca - Amphineura					
Amphineura spp. her.		3.3	5.4	0.4	0.9
		0.7	5.7	0.2	0.2
Cyanoplax dentiens her.			2.3	4.7	2.1
				0.6	0.1

Continued

Table II-D. (Contd.) b. Intertidal cobble

	Morse Creek	North Beach	Partridge Point	Shannon Point	Cherry Point
Mollusca - Gastropoda					
Collisella pelta her.	10.0	16.7	27.5	11.9	60.8
	2.8		3.1	1.7	2.1
Collisella spp. her.	150.0	16.7	5.7	29.5	42.6
	1.9	0.2	0.5	3.6	1.2
Lacuna variegata her.	240.4	295.3	1504.9	0.2	247.0
	5.6	3.3	14.1		1.9
Littorina scutulata her.		324.0	229.5	78.4	1003.7
		28.7	14.8	8.5	34.6
Littorina sitkana her.	534.3	355.3	380.8	1110.0	4.1
	49.0	4.0	50.0	221.8	0.2
Notoacmaea sp.		14.9			
		3.7			
Notoacmea persona her.			55.8	29.3	67.6
			25.1	13.6	4.4
Notoacmea scutum her.		5.3	49.2	13.9	30.1
		3.3	40.7	9.2	2.0
Nucella lamellosa pre.			10.8	15.8	11.6
			14.4	53.1	40.7
Nucella spp. pre.	0.3	12.8	2.0	2.6	0.2
	0.1	2.5	3.6	1.7	
Mollusca - Bivalvia					
Mysella tumida sus.			4.9	55.6	275.7
				0.2	1.3
Mytilus edulis sus.	36.6		5.1	29.3	326.9
	5.1		0.9	1.2	18.3
Protothaca staminea sus.	0.7			6.5	49.3
	0.2			29.3	78.2
Saxidomus giganteus sus.			1.3	1.8	4.4
			9.5	56.5	95.0

Continued

Table II-D. (Contd.) b. Intertidal cobble

	Morse Creek	North Beach	Partridge Point	Shannon Point	Cherry Point
Mollusca - Bivalvia (Contd.)					
Tresus capax sus.	5.1			0.4	0.4
	12.9			0.1	
Crustacea - Tanaidacea					
Leptochelia dubia dep.	9.6		1.1	203.0	0.6
	2.9			0.3	
Crustacea - Cirripedia					
Balanus cariosus sus.		3.3	33.2	91.9	9.7
		3.3	1.4	293.1	1.7
Balanus crenatus/Balanus	984.8	106.7	990.9	162.7	1114.0
glandula sus.	110.3	6.0	27.6	10.7	67.7
Balanus spp. sus.	1589.2	42.0		1.8	22334.0
	44.0	4.7		0.3	635.7
Chthamalus dalli sus.			264.6	157.0	988.7
			3.6	2.7	11.7
Crustacea - Amphipoda					
Gammaridea spp. dep.	2502.2	107.8	3505.5	180.6	1835.0
(*Ampithoe* sp. her., *Corophium* spp. sus./dep., *Hyale* sp. dep., *Paramoera mohri* dep.)	33.4	1.3	17.4	3.2	6.3
Crustacea - Isopoda					
Exosphaeroma spp. sca.		311.0	195.1	42.3	139.7
		7.7	1.0	0.8	0.7
Gnorimosphaeroma	37.7	126.7	135.7	74.7	346.5
oregonensis sca.	0.7	0.7	1.3	2.7	6.2
Idotea spp. sca.	17.3	395.3	440.9	61.4	22.5
	4.9	0.2	14.9	9.9	1.4

Continued

Table II-D. (Contd.) b. intertidal cobble

	Morse Creek	North Beach	Partridge Point	Shannon Point	Cherry Point
Crustacea - Decapoda					
Hemigrapsus nudus sca.		3.3	35.0	96.8	202.6
		7.7	99.7	54.5	77.6
Hemigrapsus oregonensis sca.			3.7	55.6	80.9
			27.8	14.9	14.8
Hemigrapsus spp. sca.	39.4			42.1	11.3
	33.2			5.0	0.9
Pagurus spp. dep.	38.7		42.6	101.1	98.3
	6.1		3.4	8.6	2.2
Pinnixa sp. pre.			1.1	27.9	7.4
				0.9	0.3
Insecta					
Diptera larvae spp. dep.	1988.0	6.7	4.4	1.1	13.1
	3.8	3.3			
Echinodermata					
Leptasterias hexactis pre.			20.5	1.6	42.9
			7.2	2.3	30.4

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Chlorophyta								
Enteromorpha linza							.04	
Monostroma spp.		0.5	1.3			.004	0.1	
Phaeophyta								
Alaria spp.						0.8	1.0	
Costaria costata		39.0				0.13	0.15	
Desmarestia spp.		80.0		.02		0.16	1.1	1.0
Egregia menziesii						0.4		
Laminaria sp./ *Laminaria saccharina*		24.1			8.3	0.9	0.3	9.4
Nereocystis luetkeana						0.2		
Pterygophora californica					45.8	0.4	0.3	
Rhodophyta								
Botryoglossum farlowianum		2.8				0.1	.02	
Calliarthron tuberculosum	22.5							
Callophyllus flabellulata		22.1				.05	0.1	
Gigartina spp.		.08				.03	.001	
Hollenbergia sp.		2.6				.02	.001	
Hymenena sp.						0.1	0.1	3.4
Iridaea spp.						0.4	0.1	4.6
Laurencia spectabilis		9.0				0.1	.04	0.2

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Rhodophyta (Contd.)								
Microcladia borealis		21.2				.03		
Odonthalia floccosa		0.3				0.6	0.6	0.5
Odonthalia washingtoniensis		3.2				0.1	0.1	
Opuntiella californica		5.6			3.5	.001	.003	
Plocamium tenue		0.3						
P. coccineum		49.0				0.1	0.1	
Polyneura latissima		1.8				0.1	.05	
Pterosiphonia sp.		0.8				.004	0.2	3.8
Rhodomella larix						0.1		
Rhodoptilum plumosum		3.7				0.002		
Angiosperms								
Phyllospadix scouleri						0.8	.002	
Zostera marina		0.1					0.3	39.7
Nematoda spp. dep.		0.8			295.0 1.5	278.5 0.2	58.5 0.1	8.3
Oligochaeta spp. dep.		4.2			712.5 < 1.5	1014.1 0.3	187.5	
Archiannelida								
Polygordius sp.						6.7	4.5	

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Polychaeta								
Capitellidae								
Mediomastus sp. dep.		46.7 0.1		510.0 2.0	20.5 1.5	89.4 0.2	109.4 0.2	182.5 1.1
Cirratulidae								
Chaetozone setosa dep.		88.3 0.5				111.9 0.4	72.6 0.3	16.7 0.2
Dorvilleidae								
Dorvillea annulata pre.						5.7	2.5	81.7 0.2
Protodorvillea gracilis pre.					160.0 1.5	125.2 0.1	148.1 0.1	
Goniadidae								
Glycinde picta pre.		15.0 0.1				5.4 0.1	19.7 0.2	133.3 2.0
Hesionidae								
Micropodarke dubia pre.					478.0 1.5	263.9 0.5	45.7 0.1	
Lumbrineridae								
Lumbrineris sp. dep.		2.5				46.2 2.4	3.7 0.2	129.2 5.7
Maldanidae								
Axiothella rubrocincta dep.		17.5 0.1		156.0 2.0		57.1 0.6	34.6 1.0	27.5 1.0
Nereidae								
Nereis spp. her.	84.0 0.4	0.2		70.0 2.0		12.3 9.2	20.4 2.7	17.5 0.4
Platynereis bicanaliculata her.	1107.6 0.4	2.8 0.2				61.4 8.2	42.6 7.7	

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Polychaeta (Contd.)								
Onuphidae								
Onuphis sp. sca.					147.5 1.5	382.7 2.4	12.4 0.1	41.7 6.6
Oweniidae								
Owenia fusiformis dep.		1.7				3.0	92.6 1.9	519.2 1.3
Phyllodocidae								
Hesionura coineaui pre.						100.0 0.1	5.2	
Serpulidae								
Spirorbis spp. sus.	32.6 0.4	15.8					0.8 1.5	
Sigalionidae								
Pholoe minuta pre.		10.2				12.0	13.2	112.5 0.7
Spionidae								
Polydora hamata/ *P. pygidialis* dep.		1.0			347.5 1.0	0.3		2.7
Prionospio steenstrupi dep.		108.3 0.1		106.0 2.0	80.0 1.5	13.6 0.1	67.1 0.8	16.7 0.1
Spio filicornis dep.					180.0 1.5	85.8 0.5	55.1 0.3	2.5
Spiophanes bombyx dep.		0.8				37.3 0.2	124.2 0.7	
Syllidae								
Typosyllis sp. pre.		1.2		416.0 2.0		291.9 0.5	45.8 0.1	5.8

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Terebellidae								
Thelepus crispus						69.3		
dep.						10.7		
Mollusca - Amphineura								
Lepidozona spp.						12.4	3.6	
her.						0.6	0.3	
Tonicella lineata	102.0	2.2	26.7			3.5	0.2	0.7
her.	46.4	3.4	23.5			0.3	0.4	0.5
Molusca - Gastropoda								
Acmaea mitra her.	6.2	0.3	3.5			0.6	0.1	
	1.8	1.2	5.2			0.4	0.4	
Alvinia sp. sca./		12.5				86.5	20.7	340.8
det.						0.2		1.0
Amphissa columbiana	161.2	11.2	9.8	250.0		16.0	14.3	
sca./det.	7.4	1.4	7.6	16.0		0.4	0.6	
Calliostoma ligatum	263.0		14.2			1.2	0.2	
her./pre.	58.6		12.6			0.1		
Ceratostoma		0.2	0.2					
foliatum pre.		1.3	9.1					
Fusitriton oregonensis	0.6					0.2		
pre.	43.2							
Granulina	270.0							
margaritula	2.0							
Haliotis			0.3					
kamschatkana her.			5.5					
Lacuna variegata		78.3	0.1		490.0	289.1	304.7	746.0
her.		0.8			3.5	1.9	2.7	2.8

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Mollusca - Gastropoda (Contd.)								
Lirularia lirulata her.	79.6 0.6	4.5 0.2				57.6 0.8	14.6 0.2	7.5 0.2
Margarites pupillus her.	114.00 10.00	21.3 1.1	30.2 9.5		60.0 0.5	59.4 1.1	91.3 2.0	2.2 0.1
Oceanebra lurida pre.	26.6 3.8		0.6 5.5					
Trichotropis cancellata sus.		2.5 0.3	10.2 9.3					
Mollusca - Bivalvia								
Astarte alaskensis sus.						26.4 5.8	1.0 0.1	
Axinopsida sp. sus.		4.2				0.5 0.1		210.0 2.0
Clinocardium spp. sus.		5.0 26.5			702.5 0.5	3.3 1.1	4.4 18.4	45.0 141.1
Crenella decussata sus.				6.0 2.0	330.5 1.5			
Glycymeris subobsoleta sus.						683.1 7.9	65.5 0.2	
Macoma spp. sus./dep.		65.8 2.3		86.0	5.0 1.0	8.5 0.6	32.7 3.3	50.8 25.0
Modiolus rectus sus.		2.5 0.7				3.6 1.3	5.2 40.5	1.0
Mysella tumida dep./sus.		8.3		396.0 2.0	50.0 0.5	44.0 0.1	50.4 0.1	684.2 2.8
Protothaca staminea sus.		12.8 59.5				1.5 0.3	1.9 3.7	21.7 1.0
Psephidia lordi sus.					75.5 0.5	124.7 1.2	273.9 1.3	1009.2 11.6

Continued

Table II-D. (Contd.) c. Subtidal rock and cobble

	Tongue Point	Fidalgo Head	Point George	Morse Creek	North Beach	Partridge Point	Ebey's Landing	Cherry Point
Mollusca - Bivalvia (Contd.)								
Saxidomus		5.0				6.8	6.2	
giganteus sus.		164.1				42.3	167.2	
Crustacea - Tanaidacea								
Leptochelia spp.				4806.0	175.5	179.7	284.9	111.7
dep.				2.0	1.5	0.1	0.4	0.1
Crustacea - Amphipoda								
Gammaridae spp.	4734.0	119.7		2030.0	2452.5	23.5	1603.8	99.7
dep.	7.0	1.0		4.0	4.0		7.2	0.3
(*Melita* sp. dep.)								
Crustacea - Isopoda								
Exosphaeroma spp.					395.5	66.0	5.0	0.3
sca.					1.0	0.2		
Ianiropsis spp.	192.2					17.6	5.2	
dep.	0.2							
Crustacea - Decapoda								
Cancer	14.0	12.2	0.2		15.0	20.2	6.6	3.3
oregonensis	9.2	1.1			4.5	5.5	2.8	0.2
pre.								
Heptacarpus spp.		26.7				12.1	15.1	1.0
pre.		0.4				0.3	0.3	
Pagurus spp. dep.	214.6	7.2	7.5	116.0	83.0	10.7	19.5	19.7
	7.8	0.3	1.8	8.0	3.5	0.1	0.3	0.7
Pinnixa						5.7	6.0	168.5
occidentalis						0.1	0.1	0.5
pre.								
Pugettia spp. her.	482.0	7.2				53.2	53.5	
	19.2	14.0				4.8	3.0	

Continued

Table II-D. (Contd.) d. Intertidal exposed unconsolidated

	Twin Rivers	Dungeness Spit	Ebey's Landing	Guemes South	Deadman Bay	Legoe Bay	Kydaka Beach	North Beach	West Beach	Eagle Cove
Platyhelminthes										
Turbellaria spp. pre.			42.7		2128.0	57.8 0.5			2.7	8.0
Nemertea spp. pre.			102.0 0.1	3.1	246.0	8.2 0.5		4.0 0.5	52.2	10.0
Oligochaeta spp. dep.	20.0 1.3	1.7 0.5	86.4	2.2 0.1	276.0	18.0 0.4	8.0 0.7	5.0 0.5	29.3	12.0
Polychaeta										
Arenicolidae										
Abarenicola claparedii sus./dep.								8.0 0.7		6.4
Capitellidae										
Capitella capitata dep.	56.0 0.7		4.6 0.3	5.7	2.9	0.8			0.2	
Mediomastus sp. dep.				0.1	1.7				0.1	

Continued

Table II-D. (Contd.) d. Intertidal exposed unconsolidated

	Twin Rivers	Dungeness Spit	Ebey's Landing	Guemes South	Deadman Bay	Legoe Bay	Kydaka Beach	North Beach	West Beach	Eagle Cove
Polychaeta (Contd.)										
Opheliidae										
Armandia brevis dep.			3.4	5.9 0.1	2.4	21.4 0.3			0.8	
Orbiniidae										
Scoloplos sp. dep.				0.4	0.9					14.6
Paraonidae										
Paranella platybranchia dep.					0.4		2.7 0.3	534.7 0.8	4.1	75.0
Spionidae								60.7 0.7		
Malacoceros sp. dep.	220.0 0.7		1.1	0.3	1.6				0.2	352.5
Scolelepis sp. dep.				0.3						54.4
Syllidae										
Syllis sp. pre.					16.2			36.3 0.5	0.3	84.6

Continued

Table II-D. (Contd.) d. Intertidal exposed unconsolidated

	Twin Rivers	Dungeness Spit	Ebey's Landing	Guemes South	Deadman Bay	Legoe Bay	Kydaka Beach	North Beach	West Beach	Eagle Cove
Mollusca - Gastropoda										
Lacuna variegata her.			38.0 0.2	16.1 0.2		8.2 0.8			7.9	
Crustacea - Mysidacea										
Archaeomysis grebnitzkii dep.							23.0 0.8	100.7 0.7	3.1	6.6
Crustacea - Amphipoda										
Gammaridea spp. dep.	354.7 2.0	161.7 1.5	13118.9 81.1	49.2 0.6	8838.0	1723.3 12.6	41.3 1.5	1827.4 3.6	111.3 0.4	604.7
(*Accedomoera vagor* dep., *Anisogammarus pugettensis* her., *Eohaustorius* spp. dep., *Paramoera mohri* dep., *Paraphoxus* spp. dep.)										

Continued

Table II-D. (Contd.) e. Subtidal exposed unconsolidated

	Dungeness Spit	Guemes South	West Beach
Chlorophyta			
Ulva spp.		1.2	
Rhodophyta			
Gracilariopsis sjoestedtii		0.6	
Neogardhiella baileyi		0.6	
Nemertea spp. pre.		62.5	21.7
		1.3	0.2
Polychaeta			
Capitellidae			
Mediomastus sp. dep.	915.0	139.2	33.8
	1.0	0.7	0.1
Dorvilleidae			
Onuphis sp. sca.			47.3
			11.8
Protodorvillea gracilis pre.	228.0		
	1.0		
Hesionidae			
Micropodarke dubia dep.	110.0	19.2	5.3
	1.0	0.1	
Orbiniidae			
Scoloplos pugettensis dep.			102.7
			3.3
Spionidae			
Prionospio steenstrupi dep.	73.0	7.5	2.0
	1.0	0.1	
Syllidae			
Exogone spp. pre.	254.0	32.5	1.5
	1.0	0.1	
Molluscs - Bivalvia			
Mysella tumida sus.	50.0	56.7	160.7
	2.0	0.3	0.5
Protothaca staminea		17.5	
		280.5	

Continued

Table II-D. (Contd.) e. Subtidal exposed unconsolidated

	Dungeness Spit	Guemes South	West Beach
Molluscs - Bivalvia (Contd.)			
Psephidia lordi sus.	25.0 2.0		1574.8 12.7
Saxidomus giganteus sus.		5.0 172.2	
Molluscs - Gastropoda			
Natica clausa pre.		0.8 3.7	
Nucella lamellosa pre.		2.5 1.8	0.2 0.2
Crustacea - Tanaeidacea			
Leptochelia sp. dep.	123.0 2.0	93.3 0.1	155.3 0.1
Crustacea - Cirripedia			
Balanus glandula sus.		323.7 9.0	
Crustacea - Amphipoda			
Gammaridea spp. dep.	470.0 2.0	467.3 5.7	1414.7 3.5
Echinodermata			
Dendraster excentricus dep.			0.2 15.9

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Chlorophyta								
Enteromorpha spp.					22.8	2.4		2568.0
Phaeophyta								
Fucus distichus								76.0
Rhodophyta								
Rhizoclonium sp.	*	*	*		306.0	14.0	*	
Angiosperms								
Zostera marina				300.0	5.2	944.0		736.0
Nemertea spp. pre.	74.0	222.0 1.7	25.2 1.2	5.6	48.4 1.2	31.2 1.2	131.5	20.0 2.0
Nematoda spp. det.	120.2	1092.5 2.3	150.1 3.3	2.0		36.0	3334.6	
Oligochaeta spp. det.	248.9	360.7 3.5	24460.7 2.0	2.8	140.4	14.0	8783.7	13.6
Polychaeta								
Arenicolidae								
Abarenicola sp./	2.0		827.8			26.8	209.1	
A. pacifica dep.			14.0			4.0		

Continued *present, but not quantified

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Polychaeta (Contd.)								
Capitellidae								
Capitella capitata dep.	458.0	347.0 4.0	1303.2 2.3	48.8	39.6	52.8 0.7	1472.8	19.6 0.4
Mediomastus sp. dep.	2620.0		446.0 1.2		10.0		4470.6	52.0 2.0
Notomastus tenuis dep.	38.0	65.3 2.0		2.8	17.6 0.8	31.4 1.6	13.7	92.0 4.4
Cirratulidae spp. dep. *Chaetozone* sp., *Tharyx multifilis*)	924.0		81.5 1.2				7397.5	16.0 0.6
Dorvilleidae								
Dorvillea spp. pre.	546.9		81.8 1.2		3.6		1233.7	26.4 7.2
Glyceridae								
Hemipodus borealis pre.	1.7	833.8 1.2		0.8			0.3	
Goniadidae								
Glycinde picta pre.	40.5	35.0 0.8		13.6 0.8	26.8 1.2		4.0	135.6 3.6

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Polychaeta (Contd.)								
Lumbrineridae								
Lumbrineris spp. dep.	571.2		461.5 6.8				26.2	
Maldanidae spp. dep.	167.5		444.5 0.8	0.8			305.0	
Nephtyidae								
Nephtys spp. pre.	0.6	3.7 0.7		16.0 1.6	2.0 0.4		0.3	1.6 0.8
Nereidae								
Platynereis *bicanaliculata* her.	816.2	312.8 0.5	96.8 0.5	2.0			2446.9	1.2
Opheliidae								
Armandia *brevis* dep.	456.4	211.7 0.8	50.2 1.2	17.2 2.8	6.4	4.0	2783.7	22.8 0.8

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Polychaeta (Contd.)								
Orbiniidae								
Nainereis spp. dep.	243.7		201.7 0.8				0.3	
Scoloplos spp. dep.	87.4			60.0 0.4	90.8 1.2	1.2	16.6	
Oweniidae								
Owenia fusiformis dep.	33.6	1132.3 1.3		14.0			39.7	2.0
Phyllodocidae spp. pre.	97.7	194.2 5.2	1769.3 4.6	6.4	17.2	5.6	335.6	1.2
(Eteone sp., Phyllodoce sp.)								
Polynoidae spp. pre.	63.1	57.5 2.8	81.2 1.2				159.7	
(Harmothoe imbricata)								
Sabellidae								
Manayunkia aestuarina sus./dep.	1.2				0.8		268.7	

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Polychaeta (Contd.)								
Spionidae spp. dep.	16.9	1644.1 7.5	8845.7 3.7	14.0	6.0		0.3	1.2
Malacoceros glutaeus dep.	44.8		3291.3 1.7	0.8			27.2	
Polydora spp. dep.	446.9		431.0 0.8	11.2	1.4	27.2	1070.0	24.0 0.8
Pygospio elegans sus. dep.	74.1	115.7 0.7	4754.3 1.2	8.0	9.6		47.8	
Streblospio benedicti dep.					50.8			
Syllidae								
Exogone spp. pre.	2142.0	1195.3 2.0	1366.0 1.3				2319.4	
Terebellidae								
Pista spp. dep.	437.9	158.7 2.0					47.2	
Polycirrus spp. dep.								90.0 2.4

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Polychaeta (Contd.)								
Mollusca - Bivalvia								
Clinocardium nuttallii sus.	5.6	145.3 9.5		7.6			2.5	
Cryptomya californica sus.				5.6 2.0	6.0 4.8			130.4 6.4
Macoma nasuta dep./sus.	95.6		13.7 60.3	0.8 8.0	21.6 144.4	6.8 40.0	149.4	10.0 8.0
Macoma spp. dep./sus.	23.4	28.7 5.5	32.0 2.8	23.6 4.8	6.4 2.8	6.8 3.2	33.7	44.0 9.6
Mya arenaria sus./dep.	19.7			12.0 1.2	7.6 12.4	13.6 18.4	14.1	8.0 6.4
Mysella tumida sus.	0.6	3624.2 8.0		36.0			1.2	
Mytilus edulis sus.	10.9	812.8 2.3		7.6 1.2			0.9	30.4 30.4
Protothaca staminea sus.	54.4	94.2 6.7					22.2	0.4 1.6
Tapes japonica sus.	0.7				1.2 1.6	1.2 10.8		8.0 23.2

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Mollusca - Bivalvia (Contd.)								
Transennella tantilla sus.	1196.2	242.8 2.3	1666.2 6.0			6.0	1052.8	
Tresus spp. sus.	0.6	76.8 41.5						
Molluscs - Gastropoda								
Aglaja diomedea pre.	16.6			1.2	13.6 0.4	2.0	52.5	3.6
Eubranchus olivaceous pre.					17.6			
Haminoea vesicula pre.				3.2	7.2 0.4		0.6	0.8
Lacuna variegata her.		348.3 2.2		120.0				0.8 0.1
Littorina scutulata her.	0.6			.04				22.8 1.6
Littorina sitkana her.	22.2							30.4
Nassarius mendicus pre.		5.8 2.8				22.8 2.4		0.4

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Phoronida								
Phoronopsis harmeri sus.				12.0	97.6 1.6			194.0 2.0
Crustacea - Tanaidacea								
Leptochelia dubia sus.	1779.2	6372.7 3.5	670.3 2.3		8.4	1.6	1010.0	180.0 0.8
Crustacea - Cirripedia								
Balanus glandula sus.	12.6	676.3 612.0		20.0 1.2		28.0 1.1	0.3	378.0 66.8
Crustacea - Amphipoda								
Caprella sp. dep.	190.3				1.2		435.9	6.0 0.4
Gammaridea sp. (*Corophium* sp. sus./dep., *Eohaustorius* dep., *Anisogammarus* sp. her., *Orchestia traskiana* sca., *Parophoxus* sp. dep.)	908.4	690.5 4.7	553.0 6.8	445.6	302	290.0 2.4	6395.9	316.0 2.8
Crustacea - Isopoda								
Exosphaeroma sp. sca.	5.2	420.5 4.0						

Continued

Table II-D. (Contd.) f. Intertidal protected unconsolidated

	Webb Camp	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay	Padilla Bay	Wescott Bay	Drayton Harbor
Crustacea - Isopoda (Contd.)								
Gnorimosphaeroma oregonensis sca.	74.3			0.4		0.4		
Crustacea - Decapoda								
Hemigrapsus oregonensis sca.	1.1			7.6 4.0	1.2 0.4	12.4 1.6		12.4 6.4
Pagurus spp. dep.	1.9	4.3 0.3				0.4	0.3	12.8 0.4
Pinnixa sp. pre.	26.8		22.2 1.0				20.3	
Upogebia pugettensis sus./dep.			112.7 34.3	0.6	5.2 2.8			1.0
Insecta - Dipteran larvae spp. her./dep.	2.5			4.0			122.8	
Echinodermata								
Dendraster excentricus dep.		264.8 9.5						
Leptosynapta clarki dep.		44.5 1.5	57.2 2.0	0.4		0.4		

Continued

Table II-D. (Contd.) g. Subtidal protected unconsolidated

	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay
Phaeophyta				
Laminaria saccharina			996.7	
Rhodophyta				
Gracilariopsis sjoestedti				175.0
Neogardhiella baileyi				390.0
Angiosperms				
Zostera marina			4945.0	1036.7
Nemertea spp. pre.	330.0 2.0	133.0 2.0	64.2 1.7	27.5 1.5
Nematoda spp. dep.	260.0 < 2.0	881.0 < 2.0		
Oligochaeta spp. det.		445.0 < 2.0	428.0 0.1	
Polychaeta				
Ampharetidae				
Ampharete arctica dep.		120.0 1.0	165.0 1.3	44.3 0.4
Capitellidae				
Mediomastus sp. dep.		611.0 2.0		
Chaetopteridae				
Mesochaetopterus taylori sus./dep.	158.0 < 2.0			
Phyllochaetopterus prolifica sus./dep.	413.0 < 1.0	180.0 2.0		
Spiochaetopterus costarum sus./dep.	135.0 < 2.0			
Cirratulidae				
Tharyx multifilis dep.		131.0 2.0	1.7	
Dorvilleidae				
Protodorvillea gracilis pre.		146.0 2.0		

Continued

Table II-D. (Contd.) g. Subtidal protected unconsolidated

	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay
Polychaeta (Contd.)				
Goniadidae				
Glycinde picta pre.			67.5 1.1	92.5 1.1
Hesionidae				
Micropodarke dubia dep.	758.0 2.0	521.0 2.0	3.3	
Lumbrineridae				
Lumbrineris spp. dep.			34.2 2.2	88.3 2.7
Maldanidae				
Maldane glebiflex dep.			127.5 3.1	4.2 0.2
Nicomache personata dep.		220.0 2.0		
Nereidae				
Platynereis bicanaliculata her.	1728.0 1.0	251.0 2.0		17.8 0.1
Opheliidae				
Armandia brevis dep.			247.5 0.5	50.2 0.2
Oweniidae				
Owenia fusiformis dep.	68.0 2.0	90.0 1.5	3555.8 28.0	241.0 2.7
Phyllodocidae				
Eulalia sanguinea pre.	203.0 2.0			1.7
Phyllodoce spp. pre.	517.0 2.0		22.5 0.2	4.2
Polynoidae				
Harmothoe imbricata pre.		308.0 2.0	24.3 0.4	2.5 0.2
Sabellidae				
Sabella media sus.		135.0 1.0		

Continued

Table II-D. (Contd.) g. Subtidal protected unconsolidated

	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay
Polychaeta (Contd.)				
Scalibregmidae				
Scalibregma inflatum dep.				259.2 5.8
Spionidae				
Polydora spp. dep.	578.0 2.0	36.0 2.0	50.8 0.8	362.5 1.0
Prionspio steenstrupi dep.	1180.0 2.0	156.0 2.0	30.0 0.2	8.3
Sternaspidae				
Sternaspis scutata dep.			68.3 8.2	25.0 0.8
Syllidae				
Exogone sp. pre.		1383.0 2.0		
Mollusca - Gastropoda				
Alvinia sp. sca./dep.	328.0 4.0	218.0 2.0	74.5 0.2	4.2
Margarites spp. her.		211.0 2.0	12.7 0.1	
Mollusca - Bivalvia				
Axinopsida serricata sus.			60.0 0.3	229.2 1.4
Clinocardium nuttali sus.		115.0 2.0	284.2 1.8	7.5
Crenella decussata sus.		726.0 2.0		
Macoma spp. sus./dep.	203.0 3.0	289.0 19.0	167.5 26.5	77.5 40.9
Mysella tumida sus./dep.	2183.0 3.0	865.0 2.0	1480.0 7.5	160.8 0.6
Nucula tenuis dep.			106.7 1.5	54.2 0.8

Continued

Table II-D. (Contd.) g. Subtidal protected unconsolidated

	Beckett Point	Jamestown	Birch Bay	Fidalgo Bay
Mollusca - Bivalvia				
Psephidia lordi sus.		183.0	410.8	817.2
		2.0	4.7	6.8
Tellina spp. sus./dep.	261.0		68.3	7.5
	11.0		0.8	0.6
Crustacea - Tanaidacea				
Leptochelia dubia dep.	788.0	2008.0	7.5	50.8
	2.0	2.0		
Crustacea - Amphipoda				
Gammaridea spp. dep.	3001.0	1598.0	746.2	705.5
	4.0	3.0	4.1	3.1
Crustacea - Decapoda				
Pagurus spp. dep.	158.0		6.7	0.8
	2.0		0.2	
Pinnixa occidentalis pre.			830.0	158.3
			10.4	1.7
Pugettia gracilis her.		88.0		0.8
		2.0		
Echinoderms				
Leptosynapta clarki dep.			95.8	1.7
			3.3	0.1

APPENDIX III

PERCENT OCCURRENCE, MEAN DENSITY (No./km^2) AND STANDARD DEVIATION FOR COMMON BIRD SPECIES IN INTERTIDAL/SUBTIDAL, NEARSHORE, AND OFFSHORE HABITAT TYPES

Table III-A. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal, rock (exposed rock) habitat

Species	SPRING (n=21) %	SPRING Mean Density	SPRING S.D.	SUMMER (n=6) %	SUMMER Mean Density	SUMMER S.D.
Great Blue Heron				17	0.10	0.22
Common Goldeneye						
Bufflehead	19	1.09	4.13			
Harlequin Duck	14	0.21	0.61			
White-winged Scoter	19	0.14	0.31			
Surf Scoter	19	1.76	4.20			
Black Scoter	5	0.03	0.13			
Bald Eagle	19	0.24	0.60	17	0.24	0.53
Spotted Sandpiper	5	0.03	0.13			
Glaucous-winged Gull	90	10.65	17.45	100	7.87	6.41
Western Gull						
Herring Gull						
Thayer's Gull						
California Gull						
Mew Gull	5	0.02	0.12			
Bonaparte's Gull	29	12.54	36.04			
Heermann's Gull						
Common Tern						

FALL (n=30)			WINTER (n=31)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
10	0.31	1.04	6	0.14	0.54	Great Blue Heron
			19	0.30	0.76	Common Goldeneye
			32	1.76	5.42	Bufflehead
			16	0.23	0.80	Harlequin Duck
						White-winged Scoter
			23	1.65	3.49	Surf Scoter
						Black Scoter
10	0.04	0.13	32	0.50	1.04	Bald Eagle
						Spotted Sandpiper
90	17.54	34.18	100	16.85	23.31	Glaucous-winged Gull
10	12.12	63.31				Western Gull
7	0.10	0.46				Herring Gull
			19	0.40	0.97	Thayer's Gull
33	16.35	54.68				California Gull
17	0.42	1.41	61	10.88	25.01	Mew Gull
73	124.87	231.72	26	2.85	6.66	Bonaparte's Gull
23	1.39	5.02				Heermann's Gull
17	3.52	9.66				Common Tern

Table III-B. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal rock (protected rock) habitat

Species	SPRING (n=27) %	Mean Density	S.D.	SUMMER (n=7) %	Mean Density	S.D.
Great Blue Heron						
Greater Scaup	4	0.15	0.79			
Common Goldeneye	15	0.34	0.94			
Bufflehead	30	2.33	5.12			
Oldsquaw						
Harlequin Duck	18	0.68	1.84			
White-winged Scoter	15	0.66	1.60			
Surf Scoter	41	12.44	47.67			
Bald Eagle	15	0.22	0.54			
Killdeer						
Glaucous-winged Gull	100	22.37	11.73	100	34.86	51.23
California Gull				14	0.12	0.29
Mew Gull	7	0.28	1.26			
Bonaparte's Gull	18	27.52	119.53			
Heermann's Gull						
Common Tern						

FALL (n=30)			WINTER (n=31)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
28	0.68	1.39	15	0.36	1.15	Great Blue Heron
						Greater Scaup
			44	1.78	3.02	Common Goldeneye
			82	16.16	28.21	Bufflehead
			26	1.10	2.79	Oldsquaw
			32	1.28	3.09	Harlequin Duck
						White-winged Scoter
22	2.71	8.04	62	4.62	6.39	Surf Scoter
6	0.09	0.36	26	0.45	0.95	Bald Eagle
3	0.16	0.87				Killdeer
97	42.80	98.49	100	17.45	15.42	Glaucous-winged Gull
22	0.42	0.93				California Gull
9	0.13	0.47	65	7.69	17.19	Mew Gull
87	229.12	457.33	32	35.96	153.73	Bonaparte's Gull
31	29.80	101.24				Heermann's Gull
12	0.25	0.79				Common Tern

Table III-C. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal rock (cobble) habitat

	SPRING (n=49)			SUMMER (n=16)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Great Blue Heron				6	0.05	0.18
Mallard				6	0.16	0.63
Greater Scaup	22	11.85	48.21			
Common Goldeneye	26	0.61	1.64			
Bufflehead	22	2.29	7.83			
Oldsquaw	31	5.95	24.86			
Harlequin Duck	33	3.34	14.10	19	2.93	7.64
White-winged Scoter	41	27.42	168.24	19	0.76	1.69
Surf Scoter	80	1090.17	2966.04	37	9.02	27.92
Killdeer				13	0.04	0.12
Sanderling						
Glaucous-winged Gull	80	30.44	56.78	100	13.42	11.93
California Gull				13	0.53	1.71
Mew Gull	35	18.53	72.19	6	0.03	0.12
Bonaparte's Gull	59	89.38	322.67	6	0.06	0.24
Heermann's Gull						

FALL (n=65)			WINTER (n=54)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
12	0.05	0.16				Great Blue Heron
						Mallard
			67	9.60	22.28	Greater Scaup
			70	2.61	3.87	Common Goldeneye
			74	7.58	19.56	Bufflehead
			59	2.29	3.39	Oldsquaw
43	1.58	3.44	50	1.17	1.83	Harlequin Duck
37	0.76	1.58	48	1.06	2.07	White-winged Scoter
57	8.08	14.14	100	25.14	40.64	Surf Scoter
						Killdeer
12	0.85	2.92				Sanderling
100	9.09	11.85	93	8.57	10.36	Glaucous-winged Gull
32	1.23	6.02				California Gull
25	0.76	2.71	46	2.45	6.49	Mew Gull
78	6.60	11.69	18	0.67	1.93	Bonaparte's Gull
34	5.54	17.21				Heermann's Gull

Table III-D. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal, exposed unconsolidated (mixed coarse) habitat

	SPRING (n=49)			SUMMER (n=15)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Great Blue Heron				47	1.02	2.45
Greater Scaup	24	1.65	4.60	7	0.03	0.12
Common Goldeneye	41	1.91	4.31			
Bufflehead	51	15.22	39.29			
Oldsquaw	16	0.24	0.65			
Harlequin Duck	33	0.67	2.12	13	1.95	5.25
White-winged Scoter	63	2.46	4.02	20	0.90	2.35
Surf Scoter	84	13.20	21.42	40	7.27	20.38
Black Scoter	26	1.50	5.28			
Bald Eagle				7	0.11	0.39
Killdeer				7	0.02	0.08
Glaucous-winged Gull	86	57.54	91.37	73	33.39	54.76
Western Gull						
California Gull				13	0.81	2.86
Mew Gull	35	4.69	17.02			
Bonaparte's Gull				13	1.92	6.24
Heermann's Gull						

FALL (n=81)			WINTER (n=87)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
33	0.59	1.30				Great Blue Heron
			54	6.18	11.62	Greater Scaup
			85	11.64	14.59	Common Goldeneye
			86	36.84	70.33	Bufflehead
			57	16.97	128.85	Oldsquaw
17	0.85	2.83	40	3.14	6.79	Harlequin Duck
47	7.56	16.99	60	3.28	6.69	White-winged Scoter
65	10.15	17.93	90	16.62	18.50	Surf Scoter
			65	2.75	4.32	Black Scoter
						Bald Eagle
						Killdeer
73	53.73	104.33	76	112.12	387.31	Glaucous-winged Gull
11	0.63	3.74				Western Gull
58	47.75	165.69				California Gull
33	14.35	110.82	68	47.01	225.14	Mew Gull
57	20.75	61.00				Bonaparte's Gull
47	12.87	36.87				Heermann's Gull

Table III-E. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal, exposed unconsolidated (sand) habitat

	SPRING (n=4)			SUMMER (n=3)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Great Blue Heron						
Common Goldeneye	25	3.18	5.51			
Bufflehead	25	4.55	7.87			
Oldsquaw						
Harlequin Duck						
White-winged Scoter	25	1.98	3.43			
Surf Scoter	75	6.13	3.93			
Bald Eagle	50	0.68	0.75	67	0.72	0.53
Killdeer				33	0.14	0.20
Glaucous-winged Gull	100	14.72	7.54	100	44.36	19.80
California Gull				67	0.86	0.68
Mew Gull	25	0.45	0.79	67	0.86	0.68
Bonaparte's Gull	25	19.77	34.25			
Heermann's Gull						
Common Tern						

FALL (n=10)			WINTER (n=7)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
10	0.09	0.27	29	1.17	2.51	Great Blue Heron
			14	0.39	0.95	Common Goldeneye
			100	15.83	14.63	Bufflehead
			71	2.31	2.21	Oldsquaw
			29	8.05	13.46	Harlequin Duck
20	1.21	2.89	29	0.31	0.50	White-winged Scoter
30	17.11	39.19	86	8.17	9.90	Surf Scoter
20	0.17	0.35				Bald Eagle
						Killdeer
100	103.08	131.94	100	25.83	35.05	Glaucous-winged Gull
60	9.76	19.07				California Gull
20	67.86	203.44	57	6.75	14.34	Mew Gull
60	44.06	98.88	43	3.18	7.25	Bonaparte's Gull
80	26.69	46.59				Heermann's Gull
30	50.00	142.53				Common Tern

Table III-F. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal, protected unconsolidated (mud-gravel) habitat

	SPRING (n=11)			SUMMER (n=2)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Great Blue Heron	64	0.38	0.40	100	1.45	1.33
Black Brant	64	11.08	13.25			
Common Pintail						
American Wigeon						
Greater Scaup	54	30.70	63.28			
Common Goldeneye	64	0.54	0.67			
Bufflehead	73	21.29	32.81			
Oldsquaw						
Harlequin Duck				50	0.24	0.24
White-winged Scoter	91	43.27	73.64	50	0.03	0.03
Surf Scoter	100	122.03	247.08	100	0.61	0.50
Black Scoter	91	1.89	2.83			
Western Sandpiper						
Glaucous-winged Gull	100	36.82	38.90	100	14.33	7.33
California Gull						
Mew Gull	64	1.42	1.53			
Bonaparte's Gull				50	0.03	0.03
Heermann's Gull						

FALL (n=9)			WINTER (n=12)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
100	0.97	0.72				Great Blue Heron
						Black Brant
			50	1.61	2.02	Common Pintail
11	1.47	4.16	75	11.99	19.58	American Wigeon
			83	171.45	325.27	Greater Scaup
			100	57.82	111.06	Common Goldeneye
			100	100.55	133.77	Bufflehead
			83	62.61	171.49	Oldsquaw
						Harlequin Duck
78	12.62	18.22	92	52.59	70.78	White-winged Scoter
89	9.36	13.93	100	140.63	271.15	Surf Scoter
			50	0.13	0.20	Black Scoter
11	0.80	2.27				Western Sandpiper
100	29.06	32.84	100	32.29	62.43	Glaucous-winged Gull
56	4.23	8.48				California Gull
56	0.49	0.80	100	14.42	30.61	Mew Gull
78	8.09	12.60				Bonaparte's Gull
22	0.13	0.29				Heermann's Gull

Table III-G. Percent occurrence, mean density (No./km 2) and standard deviation of common bird species in intertidal/subtidal, protected unconsolidated (mud-sand) habitat

	SPRING (n=17)			SUMMER (n=2)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Great Blue Heron				100	4.28	1.97
Black Brant	64	276.16	402.44			
American Wigeon	36	31.79	71.89			
Greater Scaup	57	11.90	22.75			
Common Goldeneye	36	10.84	32.35			
Bufflehead	57	57.80	102.58			
Harlequin Duck						
White-winged Scoter	79	14.91	34.01			
Surf Scoter	100	22.45	14.67			
Killdeer				50	1.25	1.25
Black-bellied Plover	43	4.22	12.34			
Black Turnstone				50	22.19	22.19
Glaucous-winged Gull	100	141.57	144.56	100	354.40	97.48
California Gull						
Mew Gull	29	25.94	47.62			
Bonaparte's Gull						
Heermann's Gull						

FALL (n=20)			WINTER (n=27)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
55	4.07	6.66				Great Blue Heron
			67	122.44	314.75	Black Brant
40	752.20	1695.50	89	411.26	544.59	American Wigeon
			63	42.34	93.62	Greater Scaup
			70	22.65	30.68	Common Goldeneye
			96	274.10	445.80	Bufflehead
			33	1.26	2.80	Harlequin Duck
50	11.08	26.06	74	14.59	22.67	White-winged Scoter
85	28.54	27.79	100	76.38	134.41	Surf Scoter
30	0.44	0.77				Killdeer
						Black-bellied Plover
						Black Turnstone
95	108.61	219.59	96	36.78	25.68	Glaucous-winged Gull
40	84.43	246.42				California Gull
65	7.26	14.76	70	21.61	63.17	Mew Gull
65	18.53	33.35				Bonaparte's Gull
55	2.38	5.05				Heermann's Gull

Table III-H. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in intertidal/subtidal, protected unconsolidated (mud) habitat

	SPRING (n=43)			SUMMER (n=17)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Great Blue Heron	91	1.73	1.85	100	6.75	5.39
Black Brant	77	147.25	265.36			
Mallard				41	0.16	0.36
Common Pintail						
American Wigeon						
Greater Scaup	98	65.13	127.07	76	3.30	5.08
Common Goldeneye	74	1.60	4.90			
Bufflehead	79	23.25	65.77			
Oldsquaw	58	0.86	2.24			
White-winged Scoter	79	6.15	7.88	65	1.18	1.90
Surf Scoter	95	73.71	250.21	71	2.12	2.95
Bald Eagle				59	0.04	0.05
Killdeer				71	0.77	1.88
Dunlin						
Glaucous-winged Gull	93	22.34	19.40	100	41.85	37.15
California Gull						
Ring-billed Gull				35	0.65	1.58
Mew Gull	56	7.49	17.52			
Bonaparte's Gull				59	8.99	15.19

FALL (n=72)			WINTER (n=82)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
96	5.24	5.84				Great Blue Heron
						Black Brant
						Mallard
			88	49.32	88.85	Common Pintail
			87	64.93	98.63	American Wigeon
72	47.01	145.45	99	67.51	66.91	Greater Scaup
			95	8.23	15.63	Common Goldeneye
			100	59.79	153.38	Bufflehead
						Oldsquaw
75	9.82	16.17	99	10.38	14.88	White-winged Scoter
87	18.99	46.68	96	20.48	31.24	Surf Scoter
						Bald Eagle
75	0.91	1.38				Killdeer
			82	93.35	130.32	Dunlin
97	20.38	22.09	100	14.78	16.12	Glaucous-winged Gull
72	2.64	5.13				California Gull
82	5.10	7.42				Ring-billed Gull
75	7.13	15.55	89	7.91	14.62	Mew Gull
93	29.73	144.75				Bonaparte's Gull

Table III-I. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in nearshore waters (less than 20 m) exposed unconslidated(mixed coarse) habitat

	SPRING (n=49)			SUMMER (n=15)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Common Loon	67	1.42	2.12	57	0.47	0.60
Red-throated Loon	47	0.72	1.50	20	0.12	0.30
Red-necked Grebe						
Horned Grebe	55	4.26	6.08			
Western Grebe	51	2.70	4.60			
Double-crested Cormorant	41	1.37	3.32	20	0.10	0.21
Pelagic Cormorant	92	4.71	4.07	73	2.95	5.43
Common Merganser				13	0.73	2.06
Red-breasted Merganser	65	8.26	13.43			
Glaucous-winged Gull	86	57.54	91.37	73	33.39	54.76
California Gull						
Mew Gull	35	4.69	17.02			
Bonaparte's Gull				13	1.92	6.24
Heermann's Gull						
Pigeon Guillemot	63	2.78	5.02	80	3.81	3.95
Marbled Murrelet				33	2.13	6.04
Rhinoceros Auklet				27	5.74	13.64

FALL (n=81)			WINTER (n=87)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
63	1.12	1.43	68	1.32	1.56	Common Loon
			46	0.64	1.26	Red-throated Loon
42	2.43	5.30	45	1.78	4.10	Red-necked Grebe
41	3.66	7.40	82	8.14	10.45	Horned Grebe
36	2.51	5.93	75	13.56	33.30	Western Grebe
			56	3.32	5.71	Double-crested Cormorant
47	5.85	23.21	74	5.82	8.00	Pelagic Cormorant
						Common Merganser
			72	6.29	9.79	Red-breasted Merganser
73	55.73	104.33	76	112.12	387.31	Glaucous-winged Gull
58	47.75	165.69				California Gull
			68	47.01	225.14	Mew Gull
57	20.75	61.00				Bonaparte's Gull
47	12.87	36.87				Heermann's Gull
43	1.72	3.43				Pigeon Guillemot
						Marbled Murrelet
						Rhinoceros Auklet

Table III-J. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in nearshore waters (less than 20 m) exposed unconsolidated (sand) habitat

Species	SPRING (n=4) %	Mean Density	S.D.	SUMMER (n=3) %	Mean Density	S.D.
Common Loon				33	0.30	0.43
Arctic Loon	25	0.23	0.39			
Red-necked Grebe	75	2.36	1.82			
Horned Grebe	50	0.99	1.12			
Western Grebe	50	2.77	3.40			
Double-crested Cormorant				33	0.69	0.98
Black Brant						
Pelagic Cormorant				33	0.14	0.20
Red-breasted Merganser	100	4.68	2.69			
Glaucous-winged Gull	100	14.72	7.54	100	44.36	19.80
California Gull				67	0.86	0.68
Mew Gull	25	0.45	0.79			
Bonaparte's Gull	25	19.77	34.25			
Heermann's Gull						
Common Murre	25	0.23	0.39			
Pigeon Guillemot	50	0.91	1.11	33	0.14	0.20
Marbled Murrelet				33	0.28	0.39
Rhinoceros Auklet				33	0.56	0.79

FALL (n=10)			WINTER (n=7)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
						Common Loon
			57	11.93	15.86	Arctic Loon
40	2.48	4.06	71	5.90	6.92	Red-necked Grebe
			100	13.00	9.31	Horned Grebe
			57	7.62	8.04	Western Grebe
40	0.88	1.21				Double-crested Cormorant
40	5.63	9.63				Black Brant
40	0.36	0.57				Pelagic Cormorant
			71	3.30	4.06	Red-breasted Merganser
100	103.08	131.94	100	25.83	35.05	Glaucous-winged Gull
60	9.76	19.07				California Gull
			57	6.75	14.34	Mew Gull
60	44.06	98.88	43	3.18	7.25	Bonaparte's Gull
80	26.69	46.59				Heermann's Gull
70	41.88	85.76	86	8.21	8.88	Common Murre
			43	0.51	0.66	Pigeon Guillemot
						Marbled Murrelet
40	22.85	38.63				Rhinoceros Auklet

Table III-K. Percent occurrence, mean density (No./km ^{2}) and standard deviation of common bird species in nearshore waters (less than 20 m) protected unconsolidated (mud-gravel) habitat

Species	SPRING (n=11) %	SPRING (n=11) Mean Density	SPRING (n=11) S.D.	SUMMER (n=2) %	SUMMER (n=2) Mean Density	SUMMER (n=2) S.D.
Common Loon	91	1.13	0.89	50	0.03	0.03
Red-throated Loon	64	0.28	0.47			
Red-necked Grebe	64	0.72	1.15			
Horned Grebe	82	4.30	5.54			
Western Grebe	91	21.31	30.61			
Double-crested Cormorant				50	0.26	0.26
Pelagic Cormorant	82	0.43	0.76	50	0.03	0.03
Red-breasted Merganser	100	2.58	2.29			
Glaucous-winged Gull	100	36.82	38.90	100	14.33	7.33
California Gull						
Mew Gull	64	1.42	1.53			
Bonaparte's Gull				50	0.03	0.03
Pigeon Guillemot	91	2.87	4.50	100	1.54	1.24
Marbled Murrelet				50	0.28	0.28
Rhinoceros Auklet				50	0.68	0.68

FALL (n=9)			WINTER (n=12)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
67	2.17	3.34	92	1.84	1.96	Common Loon
						Red-throated Loon
56	5.00	9.37	100	2.65	2.82	Red-necked Grebe
44	19.27	29.99	100	14.98	14.63	Horned Grebe
44	7.25	9.92	92	44.00	46.00	Western Grebe
			83	0.69	0.78	Double-crested Cormorant
			58	0.22	0.22	Pelagic Cormorant
			75	8.11	15.15	Red-breasted Merganser
100	29.06	32.84	100	32.29	65.43	Glaucous-winged Gull
56	4.23	8.48				California Gull
56	0.49	0.80	100	14.42	30.61	Mew Gull
78	8.09	12.60				Bonaparte's Gull
89	4.73	4.94	92	0.95	1.31	Pigeon Guillemot
						Marbled Murrelet
56	0.81	1.22				Rhinoceros Auklet

Table III-L. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in nearshore waters (less than 20 m) protected unconsolidated (mud-sand) habitat

Species	SPRING (n=14) %	Mean Density	S.D.	SUMMER (n=2) %	Mean Density	S.D.
Common Loon	64	1.37	1.44			
Red-throated Loon	29	0.24	0.44			
Red-necked Grebe						
Horned Grebe	50	3.25	4.42			
Western Grebe						
Double-crested Cormorant	43	0.43	0.55			
Pelagic Cormorant	57	2.91	4.42	50	0.38	0.38
Red-breasted Merganser	50	2.39	4.08			
Glaucous-winged Gull	100	141.57	144.56	100	354.40	97.48
California Gull						
Mew Gull	29	25.94	49.62			
Bonaparte's Gull						
Heermann's Gull						
Common Tern						
Common Murre						
Pigeon Guillemot	64	4.69	6.56	50	4.62	4.62
Rhinoceros Auklet	43	1.94	4.57			

FALL (n=20)			WINTER (n=27)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
60	2.15	3.36	74	2.19	2.51	Common Loon
						Red-throated Loon
			26	0.36	0.73	Red-necked Grebe
55	9.98	22.09	85	9.19	10.18	Horned Grebe
			41	19.30	50.80	Western Grebe
						Double-crested Cormorant
40	0.98	1.81	30	0.76	1.55	Pelagic Cormorant
			59	7.12	14.82	Red-breasted Merganser
95	108.61	219.59	96	36.78	25.68	Glaucous-winged Gull
40	84.43	246.42				California Gull
65	7.26	14.76	70	21.67	63.17	Mew Gull
65	18.53	33.35				Bonaparte's Gull
55	2.38	5.05				Heermann's Gull
35	4.44	8.31				Common Tern
			18	2.06	6.50	Common Murre
60	7.57	11.62	26	1.12	2.94	Pigeon Guillemot
						Rhinoceros Auklet

Table III-M. Percent occurrence, mean density (No./km ^{2}) and standard deviation of common bird species in nearshore waters (less than 20 m) protected unconsolidated (mud) habitat

	SPRING (n=43)			SUMMER (n=17)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Common Loon	86	1.12	1.29	82	0.31	0.34
Red-throated Loon	53	0.18	0.36			
Red-necked Grebe	70	0.62	0.95			
Horned Grebe	65	1.97	4.61			
Western Grebe	81	14.28	31.97	47	0.92	2.65
Double-crested Cormorant	81	1.71	1.92	76	3.00	3.48
Pelagic Cormorant						
Red-breasted Merganser	84	1.92	2.59			
Glaucous-winged Gull	93	22.34	19.40	100	41.85	37.15
California Gull				23	0.39	1.10
Ring-billed Gull				35	0.62	1.58
Mew Gull	56	7.49	17.52	23	0.03	0.06
Bonaparte's Gull	46	6.69	24.30	59	8.99	15.19
Pigeon Guillemot				47	0.31	0.69
Marbled Murrelet				47	0.31	0.73

FALL (n=72)			WINTER (n=82)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
83	1.66	2.52	96	1.32	1.41	Common Loon
			74	1.75	5.93	Red-throated Loon
69	4.19	15.19	90	1.97	3.28	Red-necked Grebe
65	3.76	7.40	96	5.95	23.57	Horned Grebe
65	20.70	36.20	91	31.38	51.99	Western Grebe
86	3.91	4.85	93	3.16	4.27	Double-crested Cormorant
			52	6.28	52.42	Pelagic Cormorant
			96	3.67	8.54	Red-breasted Merganser
97	20.38	22.09	100	14.78	16.12	Glaucous-winged Gull
72	2.64	5.13				California Gull
82	5.10	7.42				Ring-billed Gull
75	7.13	15.55	89	7.91	14.62	Mew Gull
93	29.73	144.75				Bonaparte's Gull
						Pigeon Guillemot
						Marbled Murrelet

Table III-N. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in nearshore waters (less than 20 m) protected rock (exposed rock) habitat

Species	SPRING (n=21) %	Mean Density	S.D.	SUMMER (n=6) %	Mean Density	S.D.
Common Loon	24	0.21	0.41			
Red-necked Grebe	24	0.59	1.29			
Horned Grebe	29	1.02	2.82			
Western Grebe	19	1.08	2.59			
Double-crested Cormorant						
Pelagic Cormorant	43	0.73	1.05	50	0.39	0.46
Red-breasted Merganser	43	1.81	3.46			
Glaucous-winged Gull	90	10.65	17.45	100	7.87	6.41
California Gull						
Mew Gull						
Black-legged Kittiwake				17	0.10	0.23
Bonaparte's Gull	29	12.54	36.04			
Heermann's Gull						
Common Tern						
Common Murre						
Pigeon Guillemot	33	0.84	2.01	83	4.18	2.36
Marbled Murrelet	14	0.90	2.60	17	0.20	0.44

FALL (n=30)			WINTER (n=31)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
						Common Loon
			23	0.37	0.86	Red-necked Grebe
			55	1.85	2.85	Horned Grebe
			55	9.60	28.20	Western Grebe
			19	1.08	2.71	Double-crested Cormorant
13	0.26	0.85	29	0.64	1.25	Pelagic Cormorant
			35	3.44	7.46	Red-breasted Merganser
90	17.54	34.18	100	16.85	23.31	Glaucous-winged Gull
33	16.35	54.68				California Gull
17	0.42	1.41	61	10.88	25.01	Mew Gull
						Black-legged Kittiwake
73	124.87	231.72	26	2.85	6.66	Bonaparte's Gull
23	1.39	5.02				Heermann's Gull
17	3.54	9.66				Common Tern
23	1.33	3.00				Common Murre
23	0.61	1.41				Pigeon Guillemot
27	1.73	4.82	26	0.63	1.23	Marbled Murrelet

Table III-O. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in nearshore waters (less than 20 m) rock (protected rock) habitat

	SPRING (n=27)			SUMMER (n=7)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Common Loon				29	1.07	1.82
Arctic Loon				14	0.12	0.29
Red-throated Loon	74	0.70	1.62			
Red-necked Grebe	22	1.10	3.16			
Horned Grebe	41	2.34	4.11			
Western Grebe	22	6.77	24.03			
Double-crested Cormorant				14	0.48	1.17
Pelagic Cormorant	30	1.03	1.97	29	7.40	17.40
Red-breasted Merganser	44	3.13	5.37			
Glaucous-winged Gull	100	22.37	11.73	100	34.86	51.23
California Gull				14	0.12	0.29
Mew Gull						
Black-legged Kittiwake				14	0.18	0.44
Bonaparte's Gull	18	27.52	119.53			
Heermann's Gull						
Common Murre						
Pigeon Guillemot	30	1.28	3.16	86	5.07	6.86
Marbled Murrelet	18	0.68	1.60	14	0.71	1.75
Rhinoceros Auklet				29	0.71	1.21

FALL (n=32)			WINTER (n=34)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
						Common Loon
						Arctic Loon
						Red-throated Loon
25	0.52	0.97	76	2.82	2.54	Red-necked Grebe
19	1.48	5.41	82	6.31	6.87	Horned Grebe
28	9.18	19.68	79	40.20	53.64	Western Grebe
			41	1.03	1.91	Double-crested Cormorant
			38	1.24	1.89	Pelagic Cormorant
			71	7.03	7.84	Red-breasted Merganser
97	42.80	98.49	100	17.45	15.42	Glaucous-winged Gull
22	0.42	0.93				California Gull
			65	7.69	17.19	Mew Gull
						Black-legged Kittiwake
87	229.12	457.33				Bonaparte's Gull
31	29.80	101.24				Heermann's Gull
44	61.28	261.44				Common Murre
22	1.75	4.95	38	1.47	8.03	Pigeon Guillemot
56	19.98	41.47	38	3.07	8.26	Marbled Murrelet
						Rhinoceros Auklet

Table III-P. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in nearshore waters (less than 20 m) rock (cobble) habitat

Species	SPRING (n=49) %	Mean Density	S.D.	SUMMER (n=16) %	Mean Density	S.D.
Common Loon	47	0.76	2.40	38	0.32	0.43
Arctic Loon	33	34.52	120.95	12	3.63	13.60
Red-throated Loon						
Red-necked Grebe	46	1.22	2.89			
Horned Grebe	26	0.72	1.88			
Western Grebe	39	8.45	42.78	25	0.87	2.19
Double-crested Cormorant				12	0.12	0.31
Pelagic Cormorant	33	0.68	2.84	25	0.26	0.53
Red-breasted Merganser	20	0.29	0.79			
Glaucous-winged Gull	90	30.44	56.78	100	13.42	11.93
California Gull				12	0.53	1.71
Mew Gull	35	18.53	72.19			
Bonaparte's Gull	39	89.38	322.67			
Heermann's Gull						
Common Murre						
Pigeon Guillemot	20	0.29	0.66	56	1.09	1.68
Marbled Murrelet				37	1.05	2.13
Rhinoceros Auklet				19	1.26	3.00

FALL (n=65)			WINTER (n=54)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
49	0.52	0.72	72	0.61	0.55	Common Loon
						Arctic Loon
			43	0.84	1.86	Red-throated Loon
						Red-necked Grebe
32	1.08	2.38	91	3.72	5.65	Horned Grebe
37	4.21	17.37	52	8.09	31.79	Western Grebe
						Double-crested Cormorant
48	1.15	3.14	61	1.69	3.32	Pelagic Cormorant
			76	1.78	2.14	Red-breasted Merganser
100	9.09	11.85	93	8.57	10.36	Glaucous-winged Gull
32	1.23	6.02				California Gull
			46	2.45	6.49	Mew Gull
78	6.60	11.69				Bonaparte's Gull
34	5.54	17.21				Heermann's Gull
			35	2.34	6.50	Common Murre
43	1.02	2.04				Pigeon Guillemot
43	1.01	1.86				Marbled Murrelet
						Rhinoceros Auklet

Table III-Q. Number of species, total density (No./km^2) and total biomass for birds occurring in nearshore habitats in spring 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Exposed unconsolidated, mixed coarse	16	43.88	48.53
Exposed unconsolidated, sand	9	13.74	16.92
Protected unconsolidated, mud-gravel (mixed fine)	16	36.25	54.92
Protected unconsolidated, mud-sand (Mixed fine)	12	20.28	23.33
Protected unconsolidated, mud	17	22.85	39.48
Rock, exposed rock	11	9.80	11.70
Rock, protected rock	13	23.03	31.22
Rock, cobble	15	54.28	98.05

Table III-R. Number of species, total density (No./km^2) and total biomass for birds occurring in nearshore habitats in summer 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Exposed unconsolidated, mixed coarse	12	20.21	19.32
Exposed unconsolidated, sand	6	4.81	8.80
Protected unconsolidated, mud-gravel (mixed sand)	6	3.13	2.10
Protected unconsolidated, mud-sand (mixed fine)	2	5.38	3.08
Protected unconsolidated, mud	15	5.29	11.16
Rock, exposed rock	4	4.97	2.69
Rock, protected rock	8	15.92	20.84
Rock, cobble	9	9.63	13.65

Table III-S. Number of species, total density (No./km^2) and total biomass for birds occurring in nearshore habitats in fall 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Exposed unconsolidated, mixed coarse	19	47.17	50.94
Exposed unconsolidated, sand	14	99.33	109.97
Protected unconsolidated, mud-gravel (mixed fine)	14	42.28	41.18
Protected unconsolidated, mud-sand (mixed fine)	17	38.30	31.91
Protected unconsolidated, mud	18	37.39	63.75
Rock, exposed rock	15	9.84	10.63
Rock, protected rock	13	101.08	94.30
Rock, cobble	16	30.01	35.42

Table III-T. Number of species, total density (No./km^2) and total biomass for birds occurring in nearshore habitats in winter 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Exposed unconsolidated, mixed coarse	18	55.03	81.36
Exposed unconsolidated, sand	15	62.15	77.75
Protected unconsolidated, mud-gravel (mixed fine)	18	79.82	116.18
Protected unconsolidated, mud-sand (mixed fine)	27	47.01	66.48
Protected unconsolidated, mud	19	57.97	95.66
Rock, exposed rock	15	26.20	32.94
Rock, protected rock	15	83.41	116.15
Rock, cobble	14	24.27	34.90

Table III-U. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in offshore waters (greater than 20 m) bays habitat

	SPRING (n=27)			SUMMER (n=5)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Common Loon	18	0.25	0.67			
Arctic Loon	22	0.96	2.64			
Red-necked Grebe	37	1.31	2.46			
Horned Grebe	22	1.02	2.50			
Western Grebe	78	70.60	89.99	60	2.17	2.46
Pelagic Cormorant	18	0.36	0.88			
Glaucous-winged Gull	96	6.58	6.13	100	10.86	9.84
California Gull				20	4.00	8.00
Mew Gull						
Bonaparte's Gull	33	3.80	9.72			
Common Murre	22	3.27	10.22	40	0.33	0.42
Pigeon Guillemot				20	0.09	0.18
Marbled Murrelet						
Rhinoceros Auklet						

FALL (n=26)			WINTER (n=33)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
						Common Loon
11	1.79	7.71				Arctic Loon
			58	2.67	3.64	Red-necked Grebe
8	0.26	1.00	36	2.56	8.66	Horned Grebe
35	23.74	81.48	85	123.83	172.31	Western Grebe
			27	0.55	1.29	Pelagic Cormorant
92	4.95	7.26	94	11.98	14.67	Glaucous-winged Gull
35	1.16	2.05				California Gull
8	0.06	0.20	67	3.33	6.57	Mew Gull
42	2.97	6.40	39	16.83	58.08	Bonaparte's Gull
50	76.91	256.69	79	40.35	75.86	Common Murre
						Pigeon Guillemot
			30	3.49	7.21	Marbled Murrelet
11	0.32	1.06				Rhinoceros Auklet

Table III-V. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in offshore waters (greater than 20 m) narrow passages habitat

	SPRING (n=62)			SUMMER (n=23)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Arctic Loon	35	84.15	281.11			
Red-necked Grebe	21	0.37	1.14			
Western Grebe	29	0.59	1.29			
Double-crested Cormorant	31	0.33	0.83	22	0.15	0.37
Brandt's Cormorant	37	85.68	265.05	4	0.03	0.13
Pelagic Cormorant	55	.60	1.04	17	0.07	0.20
Hooded Merganser				4	0.01	0.04
Glaucous-winged Gull	98	5.52	5.99	96	6.66	6.16
Thayer's Gull						
Mew Gull	24	0.41	1.76			
Bonaparte's Gull	33	44.88	153.74			
Common Tern						
Common Murre				4	0.01	0.06
Pigeon Guillemot	68	2.38	3.49	52	0.60	0.86
Marbled Murrelet				22	0.23	0.53
Cassin's Auklet				4	0.02	0.11
Rhinoceros Auklet				4	0.01	0.06

FALL (n=83)			WINTER (n=112)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
			68	28.17	72.80	Arctic Loon
						Red-necked Grebe
26	1.49	5.14	45	3.89	7.77	Western Grebe
26	0.42	1.52				Double-crested Cormorant
23	6.81	44.42	69	48.10	135.27	Brandt's Cormorant
			50	1.27	2.69	Pelagic Cormorant
						Hooded Merganser
95	6.09	8.71	96	12.54	25.57	Glaucous-winged Gull
			48	1.50	5.24	Thayer's Gull
46	0.78	1.98	87	20.48	65.93	Mew Gull
93	49.04	88.43				Bonaparte's Gull
55	5.46	22.71				Common Tern
			79	9.75	26.81	Common Murre
31	1.13	6.89	62	2.20	4.60	Pigeon Guillemot
39	5.05	32.62	54	1.69	2.97	Marbled Murrelet
						Cassin's Auklet
25	0.24	0.69				Rhinoceros Auklet

Table III-W. Percent occurrence, mean density (No./km ^{2}) and standard deviation of common bird species in offshore waters (greater than 20 m) broad passages habitat

	SPRING (n=48)			SUMMER (n=13)		
Species	%	Mean Density	S.D.	%	Mean Density	S.D.
Arctic Loon	17	8.59	44.53			
Red-throated Loon						
Western Grebe	21	1.71	7.65			
Double-crested Cormorant				23	0.25	0.76
Brandt's Cormorant	25	0.18	0.51			
Pelagic Cormorant	23	0.43	1.80	23	0.41	1.14
Glaucous-winged Gull	92	4.34	4.61	100	3.24	2.67
California Gull						
Mew Gull	17	0.22	0.77			
Bonaparte's Gull	19	42.19	269.51			
Heermann's Gull						
Common Murre	29	1.67	6.85	8	0.01	0.03
Pigeon Guillemot	44	0.63	0.92	31	0.47	1.03
Marbled Murrelet				8	0.01	0.03
Rhinoceros Auklet	35	0.41	0.77	31	3.73	11.94

FALL (n=64)			WINTER (n=76)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
			28	2.20	13.23	Arctic Loon
			29	0.29	0.81	Red-throated Loon
						Western Grebe
20	2.80	17.77				Double-crested Cormorant
			42	8.06	53.19	Brandt's Cormorant
16	0.15	0.66	39	0.36	0.64	Pelagic Cormorant
92	10.62	17.54	93	10.00	23.86	Glaucous-winged Gull
33	0.62	1.76				California Gull
			59	9.41	36.68	Mew Gull
47	6.17	17.51	21	6.74	38.11	Bonaparte's Gull
42	2.98	9.82				Heermann's Gull
67	42.61	70.38	92	63.77	146.00	Common Murre
16	0.16	0.52	38	0.40	0.83	Pigeon Guillemot
25	0.41	1.22	17	0.34	1.28	Marbled Murrelet
25	0.55	1.92				Rhinoceros Auklet

Table III-X. Percent occurrence, mean density (No./km^2) and standard deviation of common bird species in offshore waters (greater than 20 m) open waters habitat

Species	SPRING (n=16) %	Mean Density	S.D.	SUMMER (n=9) %	Mean Density	S.D.
Arctic Loon	25	2.12	7.22			
Wester Grebe	19	0.09	0.30	11	0.04	0.10
Fork-tailed Storm Petrel				11	0.02	0.05
Black Brant	12	0.64	2.42	11	0.01	0.04
Pelagic Cormorant	25	0.22	0.80	44	0.14	0.26
Northern Phalarope						
Parasitic Jaeger						
Glaucous-winged Gull	87	0.82	0.70	100	3.57	4.36
Herring Gull						
Thayer's Gull						
California Gull						
Mew Gull	37	0.27	0.50			
Bonaparte's Gull	44	6.20	22.63	11	1.44	4.06
Heermann's Gull						
Common Murre	62	0.80	1.98	78	0.77	1.26
Pigeon Guillemot	19	0.03	0.10	22	0.03	0.06
Ancient Murrelet						
Rhinoceros Auklet	56	1.09	1.95	67	2.30	2.63
Tufted Puffin				33	0.04	0.07

FALL (n=28)			WINTER (n=36)			
%	Mean Density	S.D.	%	Mean Density	S.D.	Species
			31	0.12	0.30	Arctic Loon
						Western Grebe
						Fork-tailed Storm Petrel
						Black Brant
			33	0.06	0.16	Pelagic Cormorant
29	0.93	3.07				Northern Phalarope
4	0.01	0.08				Parasitic Jaeger
100	8.94	14.01	100	4.94	5.70	Glaucous-winged Gull
25	0.12	0.34	31	0.18	0.67	Herring Gull
			28	0.13	0.28	Thayer's Gull
64	2.41	6.70				California Gull
33	0.22	0.47	80	3.00	8.31	Mew Gull
36	2.46	8.83	28	0.89	2.18	Bonaparte's Gull
61	1.17	3.78				Heermann's Gull
89	37.36	52.59	89	13.96	26.71	Common Murre
						Pigeon Guillemot
			31	0.97	2.24	Ancient Murrelet
50	1.86	7.08	31	0.09	0.20	Rhinoceros Auklet
						Tufted Puffin

Table III-Y. Number of species, total density (No./km^2) and total biomass for birds occurring in offshore habitats in spring 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Bays	21	103.06	164.54
Passages, narrow	29	229.29	407.93
Passages, broad	26	68.48	45.14
Open waters	23	15.62	12.88

Table III-Z. Number of species, total density (No./km^2) and total biomass for birds occurring in offshore habitats in summer 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Bays	6	17.65	22.09
Passages, narrow	14	8.29	11.52
Passages, broad	8	8.14	7.08
Open waters	15	12.80	10.32

Table III-AA. Number of species, total density (No./km^2) and total biomass for birds occurring in offshore habitats in fall 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Bays	15	118.63	137.22
Passages, narrow	30	84.50	50.79
Passages, broad	26	77.25	78.44
Open waters	30	72.17	65.49

Table III-BB. Number of species, total density (No./km^2) and total biomass for birds occurring in offshore habitats in winter 1978 and 1979, combined

Habitat	Number of Species	Total Density	Total Biomass
Bays	30	244.71	375.19
Passages, narrow	40	172.96	268.08
Passages, broad	33	122.77	125.07
Open waters	40	32.80	30.57